Drainage Design Manual
for the
City of San Luis Obispo
and portions of
San Luis Obispo County
within the SLO Creek Watershed

City of San Luis Obispo
Department of Public Works
955 Morro Street
San Luis Obispo, California 93401

County of San Luis Obispo
Flood Control District - Zone 9
1050 Monterey Street, Room 207
San Luis Obispo, California 93408

San Luis Obispo Creek
Waterway Management Plan

VOLUME III

Drainage Design Manual

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955 Morro Street
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and

County of San Luis Obispo
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February 2003

TABLE OF CONTENTS

Appendices

Figures

USERS GUIDE

This Drainage Design Manual is intended to be used for the hydrologic and hydraulic analysis and the design of channel modification and drainage structures along creeks and waterways within the City of San Luis Obispo and within unincorporated areas within San Luis Obispo County. It is intended to be used in conjunction with the City's Construction Standards and Standard Plans and Specifications for projects within the City, and for use with the County's Standard Plans and Specifications for projects in unincorporated areas.

The Drainage Design Manual has 11 sections and two Appendices.

Section 1.0 outlines the **objectives** of the Drainage Design Manual.

Section 2.0 describes the types of projects for which the City and County will conduct a **review of applicant furnished drainage plans** for consistency with this Manual.

Section 3.0 presents **Core Requirements**, which place in one section all of the drainage-related design criteria and standards a project will be required to meet.

Section 4.0 describes the **hydrologic and hydraulic analysis procedures** that are to be used in the design of drainage projects, including use of the Rational Method for runoff analysis of small projects, use of the Zone 9 computer model for runoff analysis of larger projects, and hydraulic analysis requirements for open channel areas of major and secondary waterways.

Section 5.0 provides the criteria and design standards for the **design of open channels**, including major and secondary waterways. **Design flows** are also presented for the major creeks.

Section 6.0 presents the procedures for **design of bank stabilization structures**, as well as a listing of preferred designs that incorporate biotechnical engineering principles.

Section 7.0 provides the design criteria and design **procedures for stormdrain conduits**, culverts, and open channels for minor waterways.

Section 8.0 summarizes information for the **design of drainage pumps**.

Section 9.0 provides design information for projects where **stormwater retention or detention facilities** are proposed.

Section 10.0 outlines requirements for **Erosion Control and Stormwater Management**.

Section 11.0 presents guidelines for **revegetation planning** and implementation along waterways

Appendix A is a **Glossary of Terms**

Appendix B provides a list of **design references**

DRAINAGE DESIGN MANUAL
FOR THE
CITY OF SAN LUIS OBISPO AND PORTIONS OF SAN LUIS OBISPO COUNTY
WITHIN THE SLO WATERSHED

FOREWORD

This Drainage Design Manual (Design Manual) has been developed to provide criteria and planning procedures for floodplains, waterways, channels, and closed conduits in the San Luis Obispo Creek watershed. This Drainage Manual will be used by the City of San Luis Obispo and San Luis Obispo County Flood Control and Water Conservation District Zone 9 (SLO/Zone 9) staff in their internal design of stormwater drainage, flood management and bank stabilization and restoration projects.

In addition, private property owners submitting applications for grading and building permits within the City limits, and those seeking similar permits from the County for projects within the SLO Creek watershed (Zone 9 service area) will be required to follow these guidelines and procedures. The City and County will use the design criteria in drainage facility design review and the checking of design and construction of private projects, including projects, which, upon completion, will be managed and maintained by these agencies.

Drainage facility review as used here is meant to be inclusive of the review of all drainage and hydraulic structures, including review of all supporting engineering calculations. Drainage facilities include but are not limited to: hydraulic structures, open channels, closed conduits, pipes and culverts, stormwater management structures, bank stabilization and bank repair structures, and grade control and aquatic enhancement structures that may be placed in stream channels. Guidelines for stream corridor planting and management, and bank repair and stabilization structures and devices are also provided in this Manual. General erosion control and stormwater management requirements are also included.

It is critically important that any proposed channel modification and/or drainage improvement project preserve, protect, and enhance the waterways within the SLO creek watershed, including streamside or riparian vegetation and aquatic habitat and fisheries. Although specific design criteria and design procedures are presented, the design engineer is invited to be as creative as possible in ways that provide functional, safe and aesthetically pleasing channels or waterways, which are also compatible with the environment. Alternate methods of analysis and design are subject to the approval of the City Engineer, or County Public Works Director. Early consultation with the City Engineer and Natural Resource Manager, or the County Public Works Director, and collaboration with stream geomorphologists and biologists prior to completing engineering designs that potentially impact creek resources in this watershed is strongly encouraged.

SECTION 1.0

DRAINAGE MANUAL OBJECTIVES

This Design Manual provides design guidelines and criteria to meet the following surface water management objectives:

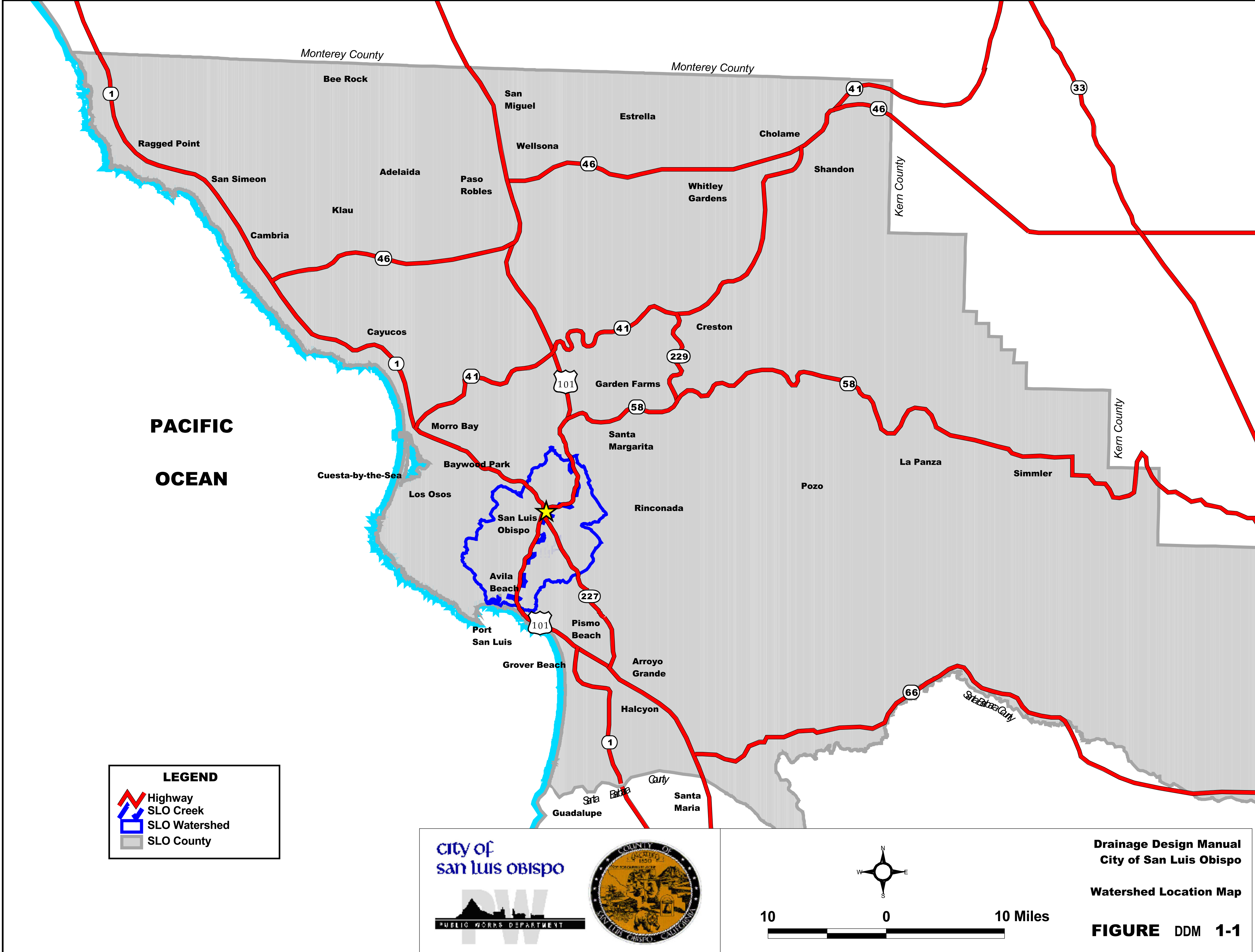
1. Insure that stormwater runoff in the San Luis Obispo (SLO) Creek watershed is adequately controlled to reduce flood and environmental damage from new development and redevelopment projects. The limits of the SLO Creek watershed that are addressed in this Manual are shown on ***Figures 1-1 and 1-2*.**

2. Insure that stormwater is carried through a system of waterways and conduits in such a way that flood water surface elevations and corresponding flood damage does not increase, damage is minimized at existing and future building sites, and existing flood water surface elevations are reduced wherever feasible;

3. Insure that the creeks, channels, and waterways remain relatively stable, or are stabilized following development or redevelopment projects, and other projects such as bank repair and hydraulic structures constructed near or along the waterways;

4. Preserve and protect natural biological resources along creeks and waterways, including their functions and values, and ensure that they are restored and enhanced wherever possible, and;

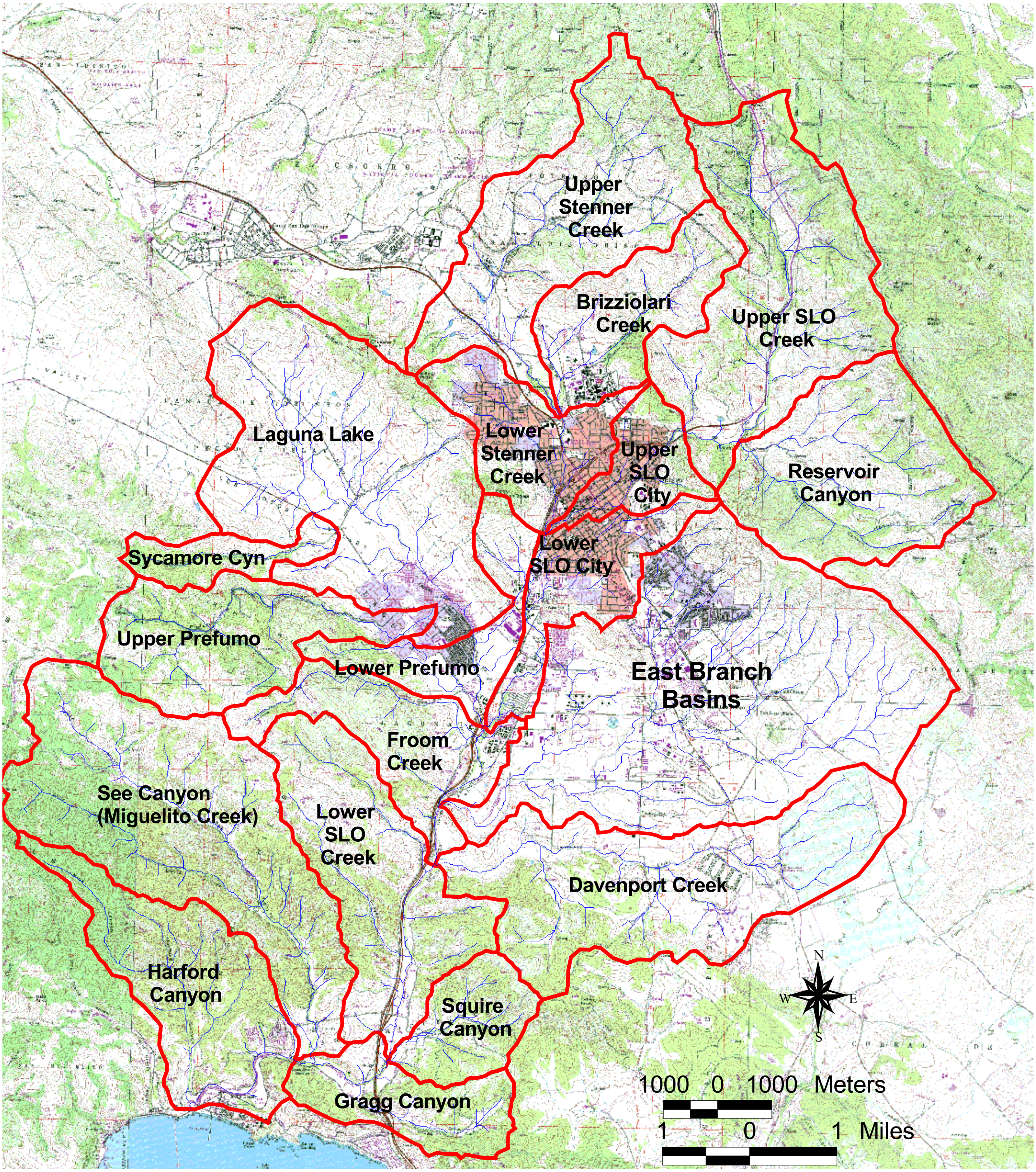
5. Protect and improve water quality.



Drainage Design Manual
City of San Luis Obispo

Watershed Location Map

FIGURE DDM **1-1**



City of San Luis Obispo
PUBLIC WORKS DEPARTMENT

Watershed and Major Sub-Basins

Drainage Design Manual
City of San Luis Obispo

QUESTA ENGINEERING CORPORATION

Figure
DDM
1-2

FILE REFERENCE: c:\arcview projects\98202 slo phase ii\98202hydrology.apr
LAYOUT: Figure 1 - Base Map B
DATE: Feb 4, 2002

SECTION 2.0

PROJECTS REQUIRING HYDROLOGY/HYDRAULICS AND DRAINAGE FACILITY DESIGN REVIEW

This Manual sets forth design criteria and submittal requirements for review of development proposals and projects along creeks and waterways within the San Luis Obispo Creek Watershed. The City and County will use these criteria in the review of projects for their impacts on creeks and waterways and for the adequacy of drainage facilities and their compliance with the policies contained in this Manual. Drainage facility design review includes a review of the following applicant-furnished information:

1. Hydrologic and hydraulic analysis, including floodplain information and floodplain determinations associated with City and County floodplain management regulations and ordinances, and this Design Manual;
2. Geomorphic and geotechnical channel stability assessments and bank repair and stabilization plans- when required by the City Engineer or County Public Works Director, and;
3. Review of all stormwater drainage facilities and hydraulic structure designs for compliance with applicable standards.

2.1 Drainage Master Plan

Preparation and submittal of a satisfactory Drainage Master Plan may be required as part of the approval process for all Specific Plans and large development projects as determined by the City Engineer or County Public Works Director. Normally a large development project will be considered to be projects over 1 hectare (2.5 acres). The Drainage Master Plan shall consider cumulative regional drainage and flooding impacts of the development proposal, including stream stability, and shall address mitigation requirements of the identified impacts. This impact assessment will be coordinated with any required CEQA Document, as determined by the City or County CEQA compliance officer. The intent of the Drainage Master Plan shall be to insure that the overall rate of runoff from a project does not significantly exceed pre-development conditions for the 2-year, 10-year, and 100-year return interval peak runoff events. If necessary, this design intent shall be achieved by incorporating runoff control measures to minimize peak flow increases (refer to **Section 9.0)**, and/or by providing assistance in financing or otherwise implementing comprehensive Drainage or Stormwater Management Plans (refer to **Section 3.2**).

2.2 Drainage Design Review

The drainage review will be completed by the City or County Public Works Departments for compliance with this Design Manual. Although all grading plans and drainage facilities are subject to the review and approval of either the City or County, a more rigorous design and more detailed drainage plan review will be completed for any proposed project located in the San Luis Obispo Creek watershed that meets the following criteria:

1. An applicant submits plans that require City or County review and approval of any of the following:

    - Grading Plan covering more than 1 ha (2.5 ac); or that involves moving more than 75 m^3 (100 yd^3) of earth
    - Master Plan Development
    - Planned Unit Development
    - Subdivision on more than 1.0 ha (2.5 ac)
    - Area Plan or Specific Plan
    - Drainage Master Plan

2. The City Community Development Department, or County Planning and Building Inspection Departments shall request the appropriate City Engineer or Public Works Department review for compliance with this Manual for all project proposals that require <u>any one</u> of the following permits or approvals:

    - Building
    - Conditional Use
    - Special Use
    - General Plan Amendment
    - Zoning Variance

    <u>and</u> the project is located:

1. within 30 meters (100 feet) of the centerline of a blue-line stream shown on the most recent U.S. Geological Survey 7.5 minute topographic quadrangle map covering the site. The stream must have an upstream drainage area or catchment over 4 ha (10 ac),

    <u>and/or</u> the project is located:

2. within a 100 year floodplain as shown on the most recent FEMA Flood Insurance Rate Map (FIRM) of the City or County area, or the 100 year floodplain shown on the Zone 9 floodplain delineation completed for the SLO Creek Waterway Management Plan.

3. <u>or</u>, is an individual development project or new redevelopment project that would add more than 930 m^2 (10,000 ft^2) of impervious surface area, or involves more than 1.0 hectare (2.5 acres) of land;

4. <u>or</u>, Requires a permit from any one of the following regulatory agencies:

- U.S. Army Corps of Engineers Section 10 or Section 404 permit;
- California Department of Fish and Game Section 1601 or 1603 Streambed Alteration Agreement;
- Central Coast Regional Water Quality Control Board Section 401 Water Quality Certification or Wavier;
- Stormwater permit issued by the Central Coast Regional Water Quality Control Board.

2.3 Submittal Requirements

Submittal of a detailed Hydrologic and Hydraulic Analysis Report is required for all proposed drainage facilities pursuant to ***Section 2.2***. This requirement is applicable to discretionary applications for proposed developments including Residential Subdivisions, Rural Subdivisions, Minor Land Divisions (parcel maps), Commercial, Industrial and Multi-Family Developments to describe the drainage related facilities associated with any of the above activities. In cases where the applicant determines that drainage improvements are minor and would not require a detailed analysis, the applicant can request, in writing, an exemption from this submittal requirement be granted by the City or County. Applications will be reviewed on a case-by-case basis when mitigating circumstances can be demonstrated by the applicant.

Provisions by the City or County Grading and Erosion Control Ordinances also require submittal of a grading and drainage plan when surface drainage is discharged onto any adjoining property. An analysis of the effect of the discharge is required to be included with the submittal.

Drainage analysis submittals shall include adequate supporting hydrologic and hydraulic information for the proposed improvements and supporting documentation including computations and any relevant information, which will assist in the review process.

Drainage analysis submittals to be provided with the design plans included in discretionary applications for major land divisions shall include a hydrologic and hydraulic analysis report. The following outlines the requirements for submittal of a Hydrologic and Hydraulic Analysis (Drainage) Report.

2.3.1 Hydrologic and Hydraulic Analysis Report

The Hydrologic and Hydraulic Analysis Report should include a complete analysis of proposed improvements and supporting documentation including computations and any relevant information, which will assist in the review process. The Report shall be prepared by a Civil Engineer who is registered in the State of California. The report shall bear the State of California Registered Professional registration seal with signature, license number and registration certification expiration date of the Engineer responsible for the preparation of the report. Where the analysis includes geotechnical support in the design, the report may require the signature of a California Registered Geotechnical Engineer, or a Certified Engineering Geologist. The following information is considered as the minimum for inclusion in the drainage study submittal.

- ***Introduction and Background***

  The introduction and background should consist of a discussion of the proposed project including existing conditions. A discussion on the purpose and scope of the drainage study and a discussion of the proposed methodology for the analysis should also be included. The report should contain a description of the project site and a location map. A discussion of the level of detail for the study and general assumptions including those associated with parameter estimations considered for the analysis should be incorporated. Existing drainage problems, including bank stability problems, or proposed alterations to existing drainage features, flows and bank conditions should be identified and thoroughly discussed. Discussion of constraints, which influence selection of available alternatives, should also be included.

- ***Location Map/Description***

  A discussion of the project area including a map identifying the location of the proposed project should be included in the study.

- ***Watershed Description/Delineation***

  The catchment tributary to project improvements and to downstream facilities being analyzed should be delineated on mapping sufficient to identify the parameters utilized in the analysis. Scale and detail should be sufficient for the level of analysis. A base map created from information on a U.S.G.S. 7.5 minute quadrangle map will be considered as minimum required for the submittal.

- ***Hydrologic Analysis***

  The hydrologic analysis should include a presentation and discussion of the results obtained by the analysis and calculations performed pursuant to the guidelines set forth in ***Section 4.0*** of this Manual.

- ***Hydraulic Analysis***

  The hydraulic analysis should include a presentation and discussion of the results obtained by the analysis and computations performed pursuant to the guidelines set for the in ***Section 4.0*** of this Manual.

- ***Geomorphic, Geotechnical and Structural Analysis of Existing and Proposed Drainage Improvements***

  The geomorphic, geotechnical and structural analysis should include a presentation and discussion of the results obtained by the field and office analysis and calculations performed pursuant to applicable guidelines set forth in Section 6.0. The analysis should also include a discussion of the condition of existing drainage facilities, geotechnical conditions and constraints (boring logs and laboratory test results), and structural integrity. A discussion of the proposed drainage facilities should also be included with respect to the similar issues. Mapping should be included in sufficient detail to identify the drainage system and analytical parameters, such as the location of existing hydraulic structures bank failure areas, and other geomorphic controls (rock outcrops, bars, nick-points, headcuts, etc.).

- ***Risk Assessment/Impacts Discussion***

  At a minimum, an evaluation of the significance of computed discharges with respect to flood protection, flood damage and impacts on the stability of the drainage system should be included in the report. Vulnerability of exposure should be determined and proposed improvement levels of protection should be justified. A discussion of any potential catastrophic losses, including associated value, should be adequately discussed when applicable.

- ***Enhancement/Mitigation***

  Proposed mitigation measures to onsite impacts and downstream drainage facilities, including riparian planting, bank stabilization, and in-stream aquatic enhancement structures should be specifically discussed.

- ***Unusual or Special Conditions***

  Any unusual or special conditions should be discussed in the report. These might include those related to existing facilities, physical or hydrological characteristics or the catchment and unusual or special requirements of the existing or proposed drainage system such as those related to operation or maintenance. Description of any special permits or special conditions required from regulatory agencies other than the City of County for the construction of proposed drainage improvements should be thoroughly discussed in the report.

- ***Conclusions***

  A conclusion section should be included in the report. Outcomes resulting from the proposed improvement analysis should be summarized and proposals, recommendations and requirements should be identified and adequately discussed.

- ***Technical Appendix of Supporting Documentation for Calculations***

  A technical appendix should be included in the report that includes documentation of the analysis, any reference materials, documentation of parameter estimations used in the analysis, historical data used in the analysis, worksheets, completed water surface profiles, cross section information and flood plain mapping, and soil boring logs and laboratory data. The appendix will be reviewed as the complete technical support data package.

SECTION 3.0

CORE REQUIREMENTS AND RESTRICTIONS FOR PLANNING & DESIGN

In general, a principal drainage design objective for a project is to ensure that new buildings and facilities are adequately protected from a design storm event, commonly by raising foundation areas and/or by conveying flow away from the building site.

Constraints are imposed on drainage design for buildings located within a 100-year floodplain because raising foundation areas or re-directing flows can potentially impact nearby stream conditions, or other properties. Additional constraints are imposed by inadequate downstream storm drain and stream channel conveyance systems and the need to minimize hydrologic impacts on these from further watershed development.

Subdivisions should be designed to contain the 10-year flood within streets, and the 100-year flood outside the building envelopes.

Eight (8) core planning and design requirements have been developed as part of this Design Manual to achieve the SLO Creek Watershed's surface water management objectives. These restrictions and requirements, and the criteria that must be met for project approval include:

1) Discharge at Natural Locations,
2) On-site Conveyance Design,
3) Off-site Runoff Analysis, Design, and Mitigation (No Adverse Impact Policy)
4) Channel Impact Assessment, Design, and Mitigation
5) Floodplain Management,
6) Bank Stabilization guidelines
7) Erosion Control requirements, and
8) Channel Maintenance and Management requirements

3.1 Discharge At Natural Locations

- Discharge from a proposed project site must occur at the existing or natural location. Under-grounding of Corps jurisdictional waterways in a closed conduit is discouraged. It is the City's and County's Policy to keep all creeks open, and that all natural channels shall be maintained in a natural condition to the maximum extent feasible, balancing flood control needs with environmental values.
- Discharge into receiving water shall be located and designed to prevent stream bank or bottom scour.

- Road crossings will be clear span structures unless the requirement is waived by the City Engineer or County Public Works Director.

3.2 On-Site Conveyance Design

- Conveyance systems must be analyzed, designed and constructed for off-site runoff of the project's catchment area using City and County General Plan build-out assumptions and developed on-site runoff for major streams are present in **Section 5.2** from the proposed project (see **Section 4.0**).
- Sizing criteria for drainage shall include analysis of parking areas and roadways, waterways, pipes, drainage inlets, and detention basins.
- Conveyance design must include an allowance for planting area in the design of Constructed Natural Channels, and for restoration and enhancement planting of Natural Channels (see **Section 5.0**).
- Projects must take into account potential future channel erosion, slope failure and creep of banks. Additional setback to bank stabilization or repair improvements allows for this natural stream activity, and provides access for site maintenance and repair.

3.3 Off-Site Facility Analysis, Design, and Mitigation *(No Adverse Impact Part A Policy)*

- All proposed projects in the SLO Creek watershed greater than 1.0 hectare (2.5 acres), including development of any portion of the site, must perform a downstream hydraulic and geomorphic analysis of potential effects from increased project runoff on drainage facility capacity, including flooding and channel instability. Subdivision of a site larger than 1.0-hectares (2.5-acres) shall be conditional on all future development meeting this standard. Guidelines for completing the hydraulic and geomorphic analysis are included in ***Section 4.2 and Section 6.0,*** respectively.
- Previously planned or designed downstream stormwater conveyance facilities (both open channels or closed conduits) must have the reserve capacity to accept projected runoff increases. If the downstream facilities do not meet the criteria stated above, a hydrologic and hydraulic analysis shall be completed pursuant to ***Section 4.0***, to identify project impacts and proposed mitigation to all downstream facilities, and show that the downstream facilities can accommodate or can be modified to accept the increased flows.
- Runoff shall be managed to prevent any significant increase in downstream peak flows, including 2-year, 10-year, 50-year, and 100-year events. Significant generally means an increase of over **5 percent** at and immediately downstream of the project site, but must be determined on a site-specific basis, considering capacity of downstream hydraulic structures, any increase in flood water surface

elevations, and existing channel stability. Cumulative hydrologic impacts shall also be considered.

- When downstream facilities are unable to accommodate increases in stormwater runoff, appropriate mitigation shall be implemented in the design. This can include channel modifications such as a Constructed Natural Channel, or By-pass Channel as defined in ***Section 5.1*** and described in ***Section 5.2*** of this Manual, or improvements to the storm drain system consistent with the design criteria of this Manual.
- Implementation of detention or retention facilities on-site, or in a regional facility to attenuate peak runoff to a level, which does not impact downstream drainage facilities, is an acceptable method of mitigation. ***Section 9.0*** provides guidance for construction of stormwater management systems. Payment of a ***Drainage Impact Fee*** to fund future planned stormwater and drainage improvement projects is another potentially acceptable method, subject to additional CEQA review. In the case of significant increases in on-site runoff, or other project-created impacts on adjacent properties and waterways, the City or County may require construction of temporary drainage controls, including local on-site detention facilities, until the regional facility or drainage improvement is constructed. It is recommended that the City Engineer and County Public Works Director develop a formula to assess ***Drainage Impact Fees*** based on the increase in impervious surface area, or increase in off-site runoff.
- The City, in cooperation with the County, shall maintain a cumulative hydrologic model representing watershed runoff and detention facility planning.

3.4 Channel Impact Assessment, Design, and Mitigation *(No Adverse Impact Part B Policy)*

- All proposed channel modification projects, including bridges, culverts, new storm drain outfalls, and bank stabilization projects impacting creeks located on a designated FEMA 100- year floodplain, or located on blue-line creeks shown on the US Geological Survey, 7.5' topographic quadrangle maps must perform an off-site hydraulic and geomorphic analysis pursuant to ***Section 6.0***. This requirement can be waived at the discretion of the City or County for small projects such as bank stabilization projects along creek banks, which impact less than 15 meters (50 feet) of creek.
- Mitigation may require the stabilization of upstream and downstream channel segments, as determined by the City Engineer or County Public Works Director, or the payment of a ***Stream Zone Impact Fee*** (for impacts to stream zone vegetation and channel conditions) to fund City or County sponsored channel stabilization and restoration projects. It is recommended that the City Engineer and County Public Works Director develop a formula to assess Stream Zone Impact Fees based on square footage of stream bank disturbance. Channel modifications are to utilize the concept of a Constructed Natural Channel

whenever possible, as outlined in ***Section 5.3.*** Bank Stabilization shall focus on the use of biotechnical methods, as described in ***Section 3.9.2 and Section 6.0.***

3.5 Floodplain Management

This Design Manual recognizes that much of the floodplain in the middle one-third (1/3) of the SLO Creek watershed has been substantially built- out, and that the City has an Urban Reserve boundary to encourage in-fill development and prevent urban sprawl. The City's policy is to encourage in-fill development, or the building or redevelopment of vacant parcels surrounded by existing developed parcels within urban areas. The floodplain has already been substantially modified within the in-fill urban areas, and significant additional off-site flood impacts are less likely to occur in these areas. The primary policy objective for these areas is to minimize flood damage to existing and new buildings, and minimize additional obstructions to flood water passage. Additional floodplain management regulations are provided for the flood prone Mid Higuera Specific Plan Area, which extends from the Marsh Street Bridge along San Luis Obispo Creek to below Madonna Road. In-fill floodplain regulations will apply to these areas.

Development of large vacant parcels located within the floodplain at the edge of the SLO urban area has a much greater likelihood of creating increased off-site flood damage. The policy objective for these areas is to prevent or minimize downstream impacts from floodplain development. Accordingly, two sets of standards and design criteria are utilized, one for ***"urban in-fill development"*** within the existing urban area, and one for ***"non- in-fill development"*** in large vacant parcel areas at the edges of the existing urban area. ***Special Floodplain Management Zones*** regulations apply to these non-in-fill areas.

Areas designated as non-in-fill development or ***Special Floodplain Management Zones*** are shown in ***Figure 3.1***. The Mid Higuera Specific Plan area is also shown on this figure**.** The City Community Development Director in consultation with the City Engineer and the County Planning Director in consultation with the County Public Works Director shall designate other areas as Special Floodplain Management Zones as appropriate, as General Plans are updated, or as needed. The following floodplain standards are in addition to other City, County, state, and federal rules and regulations governing FEMA defined 100-year floodplains and flood hazard areas. The 10 and 100-year floodplains, as determined from the SLO Waterway Management Plan, are shown in ***Figure 3-2***.

3.5.1 In-fill Floodplain Regulations

Individual new development projects on vacant parcels, and redevelopment projects within the FEMA designated 100-year floodplain that are within the in-fill areas shown in ***Figure 3-2*** (not within Mid-Higuera or special Floodplain Management Zone) have been determined to have no-significant effects on flood elevations, provided these Design Criteria are met. No significant impacts for floodwater surface elevation rise, means a cumulative increase of less than **64-mm**. (2 1/2 inches), or as determined by the City Engineer.

- All finished lowest floor elevations for new buildings, and building additions shall be at least 0.3 m (1 ft) above the defined FEMA 100-year flood elevation at time of construction, unless otherwise allowed by the City Engineer in consultation with the City Community Development Director.

- Commercial buildings located in the City's central business district can be built at present grade within the FEMA 100-year floodplain, provided the building is "flood-proofed" according to current FEMA guidelines and criteria, as approved by the City Engineer.
- The floodplain may not be modified in ways that increase water velocities such that stream bank erosion will be increased, unless the stream banks are protected to prevent the increased erosion.
- Existing nonconforming structures are allowed to remain in the in-fill floodplain management area. Existing nonconforming structures may be modified only when the structure is small relative to the structure and with approval of the City Engineer or County Public Works Director.
- Flood proofing following FEMA standards and guidelines is encouraged for existing buildings within the flood-prone in-fill areas.
- The setback from the top of bank shall be consistent with the City's existing policies for creek setback and shall be maintained as a flood passage way. No new buildings, structures, or fences that could potentially block the downstream passage of floodwaters will be permitted in this area.

3.5.2 Mid-Higuera Specific Plan Area

- For the floodplain area within the area defined by the City as the Mid-Higuera Specific Plan area, (generally extending along San Luis Obispo Creek between the Marsh Street Bridge at Highway 101 downstream to below the Madonna Road Overcrossing, (***Figure 3-2***), no building replacement, or building additions to the first floor will be permitted in a 7.5 m (25 ft) zone, as measured from top of bank. This requirement may be waived at the discretion of the Community Development Director and City Engineer for minor additions and remodeling of existing single-family housing.
- Replacement of existing buildings and structures with new buildings and structures that occupy the exact footprint (or less) of a pre-existing building will be permitted on all creek reaches of San Luis Obispo, and Stenner Creeks upstream of the Mid Higuera Specific Plan area, consistent with the City's existing creek setback policies.
- For 100-year floodplain areas extending more than 7.5 m (25 ft) from top of bank, (***Figure 3-2***) construction of new fences shall be made of permeable materials such as chain -link, wrought iron, etc. that allow relatively free passage of floodwater. Project designs shall include provision of return flow paths for overbank floodwater to San Luis Obispo Creek. Chain link fencing shall not be used where flowing water is likely to deposit debris against the fence, because the flow is perpendicular to the fence, or nearly so.

- All streets to be dedicated to the City and all City street right-of-ways running parallel to the nearest streams that cause flooding shall be designed and maintained with a minimum of obstructions to flood water passage, minimizing landscape medians, signs, benches, and other barriers to flood flow passage.
- For existing building replacement, building additions, remodeling, and redevelopment projects, no increase in the size of the building footprint of the first floor as measured in square meters is allowed. Replacement buildings must "shadow or be placed directly downstream" of existing buildings to the maximum extent feasible. This requirement may be waived at the discretion of the City Engineer for minor additions and remodeling of existing single-family housing.

3.5.3 Special Floodplain Management Zone Regulations (Managed Fill Criteria)

Development of vacant lands in Special Floodplain Management Zone areas shown on ***Figure 3-1*** have been determined to have a potentially significant effect on downstream flooding and bank stability. These potential impacts can be mitigated by incorporation of the following floodplain management policies in project design (termed ***"Managed Fill"***):

For any development or subdivision proposal within the 100- year FEMA floodplain on individual parcels or developments larger than 1.0 hectares (2.5 acres), the development proposal shall include a Concept Grading Plan and Master Drainage Plan. These Plans shall be submitted to the City or County Public Works Director for approval and shall meet the following requirements:

- There shall be no significant net increase in up-stream or downstream floodwater surface elevations for the 100-year flood at General Plan build-out as a result of changes in floodplain configuration and building construction. A significant threshold of a **64 mm (2.5 in)** increase in floodwater surface elevations or **0.1 m/s (0.3 f/s) increase** in stream velocities shall be used. This shall be demonstrated to the satisfaction of the City Engineer or County Public Works Director based on an applicant furnished hydraulic analysis pursuant to ***Section 4.2***.
- There shall be no significant net decrease in floodplain storage volume as a result of a new development or redevelopment projects. This can be achieved by a zero-net fill grading plan, balancing all fill placed on the 100-year floodplain with cut taken from other portions of the floodplain within the project area of the application, or with cut exported off site. Specifically, all fill placed in a floodplain shall be balanced with an equal amount of soil material removal (cut) and shall not decrease floodplain storage capacity at any stage of a flood (2, 10, 50, or 100-year event).

A net increase in fill in any floodplain is allowed only when all of the following conditions are also met:

- Enlarging the channel capacity through approved channel modification as a Constructed Natural Channel shall be counted towards meeting the requirement of no significant decrease in floodplain storage. This shall be demonstrated to the satisfaction of the City or County with calculations shown on the Grading Plan, and through use of the Zone 9 HEC-RAS hydraulic model, as outlined in ***Section 4.2*** of this Manual, or alternative method approved by the City Engineer or County Public Works Director.
- Where the exceptions comply with adopted Drainage Master Plans, the SLO Creek Waterway Management Plan and when all required permits and approvals have been obtained in compliance with FEMA rules and other state, and federal laws regarding fill in floodplains.
- Large areas may not be excavated in order to gain a small amount of fill in a floodplain. Excavation areas shall not exceed the fill areas by more than 50 percent of the square footage, unless approved by the City Engineer or County Public Works Director;
- Excavation to balance fill shall be located on the same parcel as the fill unless it is not reasonable or practicable to do so. In such cases, the excavation shall be constructed as a part of the same development project.
- Any excavation dug below the winter "low water" elevation shall not count toward compensating for fill since these areas would be full of water in the winter and not available to hold storm water following a rain. Winter "low water" elevation is defined as the water surface elevation during the winter when it has not rained for at least three days, and the flows resulting from storms have receded. This elevation may be determined from records, hydrologic/hydraulic studies, or field observation. Any fill placed above the 100-year floodplain will not count towards the fill volume.
- Parking facilities providing for short term parking (motor vehicles remain parked for less than18 hours per day) in the floodplain may be located at an elevation of no more than one foot below the ten-year floodplain. Long term parking (motor vehicles remain parked for greater than 18 hours without being moved) in the floodplain may be located at an elevation of no more than one foot below the 100- year floodplain.
- Excavation and fill required for the construction of detention facilities or other facilities, such as levees, shall be specifically designed to reduce or mitigate flood impacts. Levees shall not be used to create vacant buildable land.
- Excavation and fill required to restore or enhance floodplains, riparian areas, wetlands, uplands and streams, including but not limited to the planting of vegetation, installing aquatic habitat enhancement structures, and “daylighting” existing storm drains, shall be permitted as long as the design complies with all applicable City, County, state and federal standards.

- A minimum setback of 15 m (50 ft) from the top of bank shall be adopted and maintained as a flood passage way. No new structures that could significantly block the downstream passage of floodwaters (including buildings, utility and trash closures, fences and landscaping walls) are permitted in this area. Public access trails are permitted, subject to additional CEQA review on a project-specific basis. The setback area shall be planted with native plants and maintained with an allowable Manning's roughness value of no lower than 0.050 and no higher than 0.075 as calculated using the procedures outlined in this Manual.
- The finished floor elevators of all buildings shall be a minimum of 0.3 meters (one foot) above the 100- year FEMA base flood elevation.

3.6 Bank Stabilization Guidelines

3.6.1 General Intent of Bank Stabilization Guidelines and Design Requirements

Streambank erosion and bank instability are significant, on-going maintenance and management problems along many creek reaches in the SLO Creek watershed. Requirements for designing and constructing streambank stabilization structures, making repairs to existing structures, and constructing preventative bank protection devices are presented in this part of the Core Requirements. Design procedures for bank stabilization are presented in ***Section 6.0***, including procedures for design of rock slope protection. Most bank stabilization and stream management activities also have a revegetation requirement, and ***Section 11.0*** provides procedures for design and implementation of stream corridor planting and project site revegetation.

Selection of the appropriate project design is to be based on completion of a biological, geomorphic/geotechnical, and hydraulic analysis and investigation of the creek, conducted by the project applicant or the project designer. Recommended bank stabilization conceptual designs for many of the failing or unstable bank areas along SLO Creek and its major tributaries are presented in ***Section 5.4*** of the ***Waterway Management Plan***. Other design approaches to bank stabilization may be feasible and allowable (permitable by Regulatory Agencies) at these sites.

Property owners who elect to implement one of the ***Waterway Management Plan*** recommended techniques will need to conduct a detailed and site specific study to verify the appropriateness of the conceptual design recommendation, and adapt it to their specific site conditions. The detailed design should be developed by a team of professionals retained by the property owner, including a civil engineer, a hydrologist, geomorphologist and/or geotechnical engineer, and a landscape architect or revegetation specialist. Consultation with a fisheries biologist or aquatic biologist is also recommended for most sites.

3.6.2 Design Approach

The design team must use the design approach and design procedures described in ***Section 6.0***. This procedure requires the design team:

- To consider existing site geomorphic and hydraulic conditions in the design;
- To consider potential downstream geomorphic consequences of the design;
- To consider possible effects on flooding from any stream encroachment or change in roughness, and;
- Select the softest approach to achieve a stable condition, and integrate native planting into the design, to the maximum extent feasible.

3.6.3 Design Review

- The proposed design will be reviewed by the City or County, and if appropriate, and following any necessary revisions, included in the Annual Work Plan (AWP) submitted by the City or County to the Corps as part of an Individual Permit (RGP) agreement anticipated to be issued, associated with the SLO Creek Stream Maintenance and Management Program (SMMP). Submittals of the AWP would also be made to the National Marine Fisheries Services, the US Fish and Wildlife Service, the California Department of Fish and Game, and the Central Coast Regional Water Quality Control Board as part of a proposed Memorandum of Understanding (MOU) with these agencies.
- All property owners will retain the right to submit their own proposed design and independent application to the Corps, Regional Water Quality Control Board, and the California Department of Fish and Game for separate consideration as an Individual Permit, or for some very small projects, a Nationwide Permit 13 (Bank Stabilization). However, the individual property owner will not be able to take advantage of the time and cost effectiveness, and permit streamlining created by the Programmatic CEQA document for the WMP, and any agency issued Individual Permit (IP) and/or MOU.
- Much of the information necessary to complete these analyses are contained in the ***San Luis Obispo Creek Waterway Management Plan***, and supporting Appendices, available from the City and Zone 9. The intent of this section is to require that the project designer review this information, supplement it where necessary, and actually use the information in the design of the bank stabilization and revegetation projects. Of particular importance are the maps illustrating existing bank instabilities, which the designer must consider where they occur immediately downstream (within 300 m of 1,000 ft), and information on channel bed incision, for design of the appropriate toe of hard structures.

3.6.4 Preference for Vegetative and Biotechnical Approaches to Bank Stabilization

- The ***Section 6.0*** design procedures require that the project designer give first consideration to the use of a vegetative or Biotechnical (also referred to as soil bioengineering) approach to bank stabilization. Structural approaches are discouraged. This is consistent with the ***SLO Creek Stream Management and Maintenance Program*** document.

3.6.5 Limitations On Use of Structural Approaches to Bank Stabilization

- Structural approaches to bank protection will only be considered at highly constrained sites; those sites with limited top of bank work area, or that present unusual geotechnical bank instabilities and/or that have high velocities and bank shear forces that preclude the use of vegetative and biotechnical approaches to bank stabilization. The amount of land available at top of bank and the need to protect valuable bank top improvements and infrastructure also needs to be factored into the analysis and selection of the appropriate stabilization design. This provides a basis to consider what is at risk at top of bank. The presence of these design constraints must be demonstrated in a Concept Plan and Design Report that the City or County will require the applicant for a grading and/or building permit submit for each project impacting the stream corridor.
- The use of purely structural and hard armoring approaches to bank stabilization within the SLO watershed is to be avoided, except where justified by unusual site constraints. Private property owners along the creek are advised that it will be difficult to obtain the necessary local, state, and federal permits for purely structural approaches to bank stabilization, particularly gabion, sheet pile and concrete wall structures. Where structural and hard components are proposed, they should be used only in small segments, be minimized to toe and lower slope applications, consistent with good engineering practices and include native planting components wherever possible. Generally purely hard or structural approaches that do not include native plantings or other on-site mitigation measures will be difficult to obtain permits for from either City or County approval agencies if they are over 15 meters (50 feet) in cumulative creek length.

3.6.6 Retrofitting and Repair or Replacement of Existing Hydraulic Structures and Revetments

There are many old, damaged and failing bank revetment structures that line the streams in urban portions of San Luis Obispo Creek and major tributaries. In many cases these were designed and constructed by private property owners, installed prior to 1982, and do not meet current

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[1] ***Biotechnical.*** An applied science that combines structural, biological and ecological concepts to construct living structures for erosion, sediment and flood control.

environmental or engineering standards of practice for construction durability, strength and stability.

- As part of the Stream Management and Maintenance Program, the SLO/Zone 9 will consider a phased program to remove, replace, and where possible to retrofit failing hard revetments, and those in need of repair. **Section 6.2** of the Design Manual requires the City or County and private property owners with failing or damaged structures (and that request a grading or building permit to reconstruct) consider replacement with a biotechical or integrated (planted) structural approach.

3.7 Erosion Control and Stormwater Quality Management

3.7.1 Erosion Control and Stormwater Quality Requirements

This section provides regulation of stormwater runoff for water quality protection. The City and County will prohibit all visible or measurable erosion or other stormwater pollutants from entering a public or private stormwater drainage structure, surface water drainage system or other properties. The owner of a property, issued a permit by the City, County, or Central Coast Regional Water Quality Control Board (Regional Board), together with any person or persons, including but not limited to the Contractor, causing such erosion and stormwater pollution, shall be held responsible for violation of these rules, for the timely correction of all noted deficiencies and violations, and for the prompt repair of all damages.

- No person shall create erosion by dragging, dropping, tracking, or otherwise placing or depositing, or permitting to be deposited, mud, dirt, rock or other such debris upon a public street or into any part of the public or private storm and surface water system. Any such deposit of material shall be immediately removed using hand labor or mechanical means.
- No material shall be washed or flushed into any part of the storm and surface water system until all mechanical means to remove the debris have been exhausted and preventative sediment filtration is in place. The owner of the property, permitted under a Construction Stormwater Permit Agreement, together with any person or persons, including but not limited to the Contractor or the design Engineer who causes such erosion, shall be held responsible for violation of these rules.
- It is a City and County requirement to reduce the amount of sediment and other pollutants reaching the public storm and surface water system resulting from development, construction, grading, excavating, clearing, and any other activity which accelerates erosion, to the limits prescribed in this Section.
- It is the policy of the City and County to require temporary and permanent measures for all construction projects to lessen the adverse effects of construction on the environment. All projects shall include properly installed, operated, and maintained temporary and permanent erosion control measures as provided in this section and/or in an approved plan, designed to protect the environment during the term of the project. Additionally,

compliance with the measures prescribed in this Section and/or in an approved Erosion Control Plan do not alleviate or diminish the necessity to provide effective and comprehensive erosion prevention and sediment control, as described in ***Section 10.0.***

3.7.2 Erosion Control Planning Requirements

The City and/or County will require the design and installation of soil erosion and sediment control measures for all projects located within the SLO watershed:

- Which require a grading plan, or a building plan where the City Engineer or County Public Works Director determines that substantial soil disturbance might occur, or;
- Where the project includes soil disturbance in what the City Engineer or County Works Director determines to be ***critical areas***. Critical areas include slopes equal to or greater than 10%, highly erosive and unstable land forms, and all sites within 30 m (100 ft) from the top of bank of a blue line stream shown on the latest edition of a U.S. Geological Survey 7.5 minute Topographic Map covering the proposed project area.

Two levels of soil erosion and sediment control planning and implementation are included in this Drainage Manual: ***A) Standard Erosion Control Measures, and B) Detailed Erosion Control Plans***. Determination of which approach is required will be based on project size, slope, location near a stream, wetland, or other sensitive area and whether the site is considered to be a critical site.

A. Standard Erosion Control Measures. For projects less than 1 hectare (2.5 acres) in size, and where soil disturbance will occur on slopes of less than 10%, and where the disturbed areas do not occur within 30 meters (100 feet) of a blue-line stream, as shown on the most recent version of a U.S. Geological Survey issued 7.5' topographic map, the project applicant shall implement Standard Erosion Control Measures as contained in ***Section 10.0.***

B. Detailed Erosion Control Plan. For projects over 2.5 hectares in size, or the project occurs on slopes greater than or equal to 10%, or on critical sites and unstable landforms, or within 30 meters (100 feet) of a blue line stream, the project applicant shall prepare and implement a detailed Erosion Control Plan. Guidelines and requirements for Plan preparation are contained in ***Section 10.0.***

3.7.3 Stormwater Management Procedures

The City of San Luis Obispo Municipal code Title 13 and San Luis Obispo County Code Title 22 prohibit the discharge of any pollutants or toxic substances into public stormwater systems or surface drainage. **Section 10.6** provides **Standard Procedures for the Control of Runoff into Stormdrains and Watercourses** that are intended to implement the objectives of City Code Title 13 and/or County Code Title 22. The City and/or County will require implementation of the procedures contained in **Section 10.6** as a condition of all permits issued by the respective Public Works/Engineering and Community Development (Planning/Building) Departments.

3.8 Channel Maintenance and Management

- Master Drainage Plans shall consider channel maintenance and management as a means of reducing flood damage and bank erosion. Channel maintenance and management can reduce flood damages by creating a more efficient channel, and by removal of floating debris, which can clog or reduce the capacity of culverts and bridges. Channel maintenance can also include preventive and remedial measures to reduce bank erosion and failure at critical locations.
- A Channel Maintenance and Management Program shall be prepared for each Master Drainage Plan. This Plan shall identify the types and frequency of maintenance procedures required to accomplish identified maintenance goals and objectives. The Plan must be consistent with the ***SLO Creek Stream Management and Maintenance Program, Volume II*** (SMMP) adopted by Zone 9 and the City.
- Maintenance, operation, and repair of all drainage facilities, including bank repairs, and stormwater management facilities constructed or modified by a proposed project applicant, is the responsibility of the property owner unless and until dedicated to the City or County.
- The City or County may assume maintenance responsibility of drainage facilities constructed for commercial or industrial properties, or residential subdivisions **five years** after final construction approval, the filing of an as-built report, successful completion of all mitigation and monitoring requirements that are imposed by any regulatory agency for work along a stream or wetland as determined by that agency, and acceptance of dedication.
- Maintenance must adhere to the ***Waterway Management Plan*** and specifically the ***SLO Creek Stream Management and Maintenance Program***, (SMMP).

SECTION 4.0

HYDROLOGIC & HYDRAULIC ANALYSIS

4.1 Hydrologic Analysis

4.1.1 General

This section defines the minimum requirements for hydrologic analysis within the San Luis Obispo Creek Watershed. Two analysis techniques are presented herein–one for catchments with a total drainage area above the point in question of less than 40 hectares (100 acres), and one for catchments with an area greater than 40 hectares (100 acres). The first technique utilizes the Rational Method to compute peak flow rates. The second utilizes the HEC-HMS rainfall-runoff model developed for the entire San Luis Obispo Creek watershed as part of the SLO Waterway Management Plan. Watershed sub-basins in this model can be re-delineated, and sub-basin parameters redefined, to compute 24-hour design storm hydrographs at concentration points not already defined in this model.

4.1.2 Use of Rational Method for Drainage Facility Design for Catchments Under 40 Hectares (100 Acres)

The design discharge for areas proposed for building development and redevelopment not to exceed 40 hectares (100 acres) in catchment or contributing drainage area can be made using the ***Rational Method***. This method is the most commonly used method of determining peak discharge from small drainage areas and is traditionally used to size storm sewers, channels, and other drainage structures which handle runoff from drainage areas less than 40 hectares (100 acres). This method is not applicable for routing stormwater through a detention basin or for developing a runoff hydrograph.

The Rational Method is based on empirical data and hypothetical rainfall-runoff events, which are assumed to model natural storm events. During an actual storm event, the peak discharge is dependent on many factors including antecedent moisture conditions; rainfall magnitude, intensity, duration, and distribution; and, the effects of infiltration, detention, retention, and flow routing throughout the watershed.

The accuracy of the Rational Method is highly dependent upon the judgment and experience of the user. The method's simplicity belies the complexity in predicting a watershed's response to a rainfall event, especially when the Rational Method is used to predict post-development runoff. For that reason, the engineer must select the appropriate runoff coefficient(s) and determine the time of concentration based on plan information (including proposed hydrologic changes) and experience in working with development and its effects on hydrology within the watershed. This section contains guidance and criteria on selecting appropriate formula factors.

Equation 1

The Rational Method equation is $\mathbf{Q = \frac{C * i * C_a * A}{K_c}}$; where

Q	=	Peak rate of runoff in cubic meters per second
C	=	Runoff coefficient, an empirical coefficient representing a relationship between rainfall and runoff (***Table 4-1***)
i	=	Average intensity of rainfall for the time of concentration (Tc) for a selected design storm (***Tables 4-3 through 4-6***) in mm/hr
$\mathbf{C_a}$	=	Antecedent moisture factor (see ***Table 4- 2***)
A	=	Drainage areas in hectares.
$\mathbf{K_c}$	=	Unit conversion factor equal to 360 (1 in English Units)

Runoff Coefficients

The engineer must use judgment in selecting the appropriate runoff coefficient within the range of values for the landuse. Generally, areas with impermeable soils, moderate to steep slopes, and sparse vegetation should be assigned the highest values. **Table 4-1** provides runoff coefficients to be used in the SLO watershed based on land use, soils, and slope. When using the Rational Method, a composite weighted C value may be calculated if land use within the watershed is varied. Roadway areas must be calculated and used within the composite calculation.

Equation 2

$$\sum C_1 \left(\frac{\text{Area } C_1}{\text{Total Area}}\right) + C_2 \left(\frac{\text{Area } C_2}{\text{Total Area}}\right) + \ldots = \text{Composite C value}$$

Table 4-1
Runoff Coefficients

Type of Developments	Hydrologic Soil Group	Run-off Coefficients for Slopes		
		<2%	2-10%	>10%
Single-Family Residential Lots				
1,860 sq. m (20,000 sq. ft.)	D	0.40	0.45	0.55
	C	0.30	0.40	0.50
930 sq. m (10,000 sq. ft.)	D	0.40	0.50	0.60
"	C	0.35	0.40	0.50
560 sq. m (6,000 sq. ft.)	D	0.50	0.60	0.65
"	C	0.45	0.50	0.60
Apartments				
1,800 sq. ft. (167 sq. m)	C	0.60	0.70	0.80
"	D	0.50	0.60	0.70
Heavy Industrial	D	0.85	0.87	0.90
	C	0.80	0.85	0.87
Light Industrial	D	0.80	0.85	0.87
"	C	0.70	0.75	.80
Downtown Commercial	D	0.85	0.87	0.90
"	C	0.80	0.82	0.85
Neighborhood Commercial	D	0.65	0.75	0.80
	C	.50	0.60	0.70
Dense Vegetation	D	0.25	0.30	0.40
(oak woodland, brushland)	C	0.20	0.25	0.35
Moderate Vegetation	D	0.25	0.35	0.45
(grasslands w/scattered trees & brush)	C	0.25	0.30	0.35
Sparse Vegetation	D	0.40	0.45	0.50
(grasslands and pasture)	C	0.30	0.35	0.40
Agricultural	D	0.20	0.20	0.25
(cropland)	C	0.15	0.15	0.20
Impervious Surfaces		0.85	0.87	
(streets, parking lots, garages and roofs)		0.80	0.85	0.90
Unimproved Vacant Lands	D	0.15	0.20	0.30
(parks, cemeteries, golf courses, and lawns)	C	0.10	0.15	0.20

Notes:

These values are intended to be a minimum; higher values may be required by the City Engineer or County Public Works Director.

Hydrologic Soil Group

C = Sandy Loam, Gravel, Loam
D = Clay, Adobe, Shallow Soil and/or Rockland. Refer to USDA San Luis Obispo Area Soil Survey for hydrologic soil groups.

Hydrologic design shall be based upon the current City and County General Plans for areas within the City of San Luis Obispo Urban Reserve Line, and existing County developed areas. Hydrologic analysis shall be based upon an assumed development of the tributary watersheds for valley areas and gently sloping uplands outside of the City of San Luis Obispo's Urban Reserve Line, which are undeveloped at the time of design. Gently sloping areas are defined as areas having average slopes of less than 15%. These areas shall be assumed to be developed as single family residential on large lots (lots 1.0 hectare or 2.5 acres in size) unless a publicly proposed development, Specific Plan, or the current City or County General Plans indicate a different land use.

Areas of moderate terrain shall be assumed to be developed to an intensity of use compatible with the nature of the terrain, considering slope and geologic stability. Moderate terrain is defined as terrain whose average slope is between 15 and 35%. For purposes of hydrologic analysis the building intensity of these areas shall be assumed to be single family residences on lots larger than 2 hectares (5 acres), unless a Specific Plan or the City and County General Plans indicates a different land use. Terrain with average slopes steeper than 35% shall be assumed to be permanent open space, or as shown on the respective City and County General Plans.

Public parks, golf courses and other publicly owned areas may be considered as grassed open space areas.

Time of Concentration

Time of concentration is the time required for runoff to flow from the most hydraulically remote part of the drainage area to the point under consideration. As run-off moves down the hydrologic flow path, flow is characterized into three types or regimes:

- *Overland Flow*
- *Shallow Concentrated Flow*
- *Channel or Pipe Flow*

Procedures for estimating the time associated with each of these flow types are presented in the following sections.

- **Overland Flow** (or sheet flow) is shallow flow (usually less than on 25 mm, or 1 inch deep) over planar surfaces. For the purposes of determining time of concentration, overland flow occurs in the upper reaches of the basin. The length of the overland flow is usually less than 90 m (300 ft) prior to entering shallow concentrated flow path. The recommended maximum length for this type of flow is 90 m (300 ft). The actual length varies considerably according to actual field conditions and should be verified by field investigation. Where detailed topographic mapping is available along the ridgeline, the overland flow distance can be estimated by measuring the distance from the top of the ridgeline to the first instance of "reverse curving of "V"-shaped contour lines, which generally indicate a defined swale of gully.

  The travel time for overland flow may be determined by using the Overland Flow Chart (Seelye Chart) on ***Figure 4-1.***

- **Shallow Concentrated Flow** occurs where overland flow converges to form small rills or gullies and swales. Shallow concentrated flow can exist in small, man-made drainage ditches (paved and unpaved) and in curb gutters. The recommended maximum length for shallow concentrated flow is 300 m (1000 ft).

  Determine the velocity of the flow using Equation 3.
  Then calculate the travel time by following Equation 4.

  Equation 3: $V = K_u \, k \, S_p^{\;0.5}$

  Where:
  V = velocity (m/s)
  K_u = 1.0 (3.28 in Imperial Units)
  k = interception coefficient (**Table 4-2**)
  S_p = Slope (percent)

Table 4-2
Interception Coefficients for Velocity vs. Slope Relationship of Equation 3

Flow Regime	k
Grassed waterway	0.457
Unpaved	0.491
Paved area; small upland gullies	0.619

Equation 4

$$T_t(\text{minutes}) = \frac{L}{60\,V}$$

Where:
L = length of shallow concentrated flow (m)
V = velocity (m/s, from Equation 3)

Note: The calculation of shallow concentrated flow time is frequently not included when using the Rational Method. However, the procedure is included in this Manual for consistency with other runoff methods.

- **Channel or Pipe Flow** occurs where flow converges in gullies, ditches, and natural or man-made water conveyances. Channel flow is assumed to exist in streams or where there is a well-defined channel cross-section. Use Manning's Equation for calculating channel flow. For the purposes of these calculations, it is acceptable to assume flow is bankfull depth for open channels and pipefull flow for storm drainpipes. If these assumptions appear to result in over-conservative estimates, the flow rate obtained from the initial bankfull Tc estimate can be used to recalculate channel velocity using the Manning Equation. A separate computation should be made where channel/pipe conditions change.

Equation 5

$$V = \frac{1 R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$$

Where:

V = average velocity (m/s)
R = hydraulic radius (m); $r = A/P_w$
A = cross sectional flow area (m^2)
P_w = wetted perimeter (m)
S = slope of the grade line (channel slope, m/m)
n = Manning's roughness coefficient. See Table *

Calculate the velocity (V), and then calculate the travel time using Equation 4:

Calculation of Time of Concentration

Time of concentration equals the summation of the travel time for each flow regime within the drainage area.

Equation 6

$$T_c = T_{c\ overland} + T_{c\ shallow\ conc} + T_{c\ channel\ 1} + \ldots + T_{c\ channel\ n}$$

The minimum time of concentration shall be 10 minutes.

Antecedent Moisture Regime

The Rational Method has been revised for use in the SLO watershed to include consideration of antecedent moisture conditions. Traditional application of the Rational Method does not account for soil saturation or base flow caused by previous storms or rainfall cells. However, especially in San Luis Obispo, large wintertime storms often occur in series, so that peak runoff rates are greatly influenced by rainfall that may have occurred hours or days before the most intense rainfall cell. The antecedent moisture factors shown in **Table 4-2** are an attempt to account for changes in soil infiltration capacity and creek base flow rates that occur during these very wet periods. They will be considered to apply even within highly impervious areas (such as parking lots) since baseflow in channels and/or pipes draining these areas would likely be elevated prior to especially large storm events.

Table 4-2. Required Antecedent Moisture Factors

Recurrence Interval (years)	Antecedent Moisture Factor (C_a)
2 to 10	1.0
25	1.1
50	1.2
100	1.25

4.1.3 General Procedure for the Rational Method

The general procedure for determining peak discharge at a given concentration point using the Rational Method is as follows:

Step 1 - Determine the drainage area (in hectares).

Step 2 - Determine the runoff coefficient (c) for the drainage area, using ***Table 4-1***. If the landuse and soil cover are homogeneous for the entire drainage area, a single runoff coefficient value can be determine directly from the table. If there are multiple landuses or soil conditions, a weighted average must be calculated as follows:

Step 3 - Determine the hydraulic length or flow path that will be used to determine the time of concentration. Also, determine the types of flow (or flow regimes) that occur along the flow path.

Step 4 - Determine the time of concentration (T_c) for the drainage area for each subarea and flow path. Add all of the travel times to get the time of concentration (T_c) for the entire hydraulic length or flow path.

Step 5 - Determine the Rainfall Intensity Factor (i) for the selected design storm by using the Rainfall Intensity charts (***Tables 4-3 to 4-6***). Select the chart with average annual rainfall for the locality closest to project, as shown on ***Figure 4-A and 4-B***.

Step 6- - Determine Antecedent Moisture Factor from **Table 4-2** based on the design storm being considered (i.e. 2- yr, 10-yr, etc)

Step 7 - Determine the peak discharge according to ***Equation 4-1***.

This procedure can be repeated for each concentration point as one moves down a given drainage system. At each point, a new T_c will need to be completed by adding the channel time between the previous concentration point and the new point to the previously estimated T_c (per ***Equation 4-6***). A new run-off coefficient will be computed pursuant to ***Equation 4-2***, and new rainfall intensity; from ***Tables 4-3*** to ***4-6***.

Table 4-3

Rainfall - Intensity Data (mm/hr), Areas With < 350 mm Annual Rainfall

Recurrence Interval (years)	**Duration**							
	10 min	15 min	30 min	1 hr	2 hrs	3 hrs	6 hrs	10 hrs
2	25	23	13	10	6.6	5.6	4.6	3.6
5	36	30	20	13	8.1		6.3	5.1
10	43	36	25	15	9.7		7.6	5.8
25	51	43	28	18	12		9.4	7.1
50	56	48	33	20	14		11	8.6
100	61	53	36	23	15		12	9.1

Table 4-4

Rainfall - Intensity Data (mm/hr), Areas With 350 mm to 450 mm Annual Rainfall

Recurrence Interval (years)	**Duration**							
	10 min	15 min	30 min	1 hr	2 hrs	3 hrs	6 hrs	10 hrs
2	33	28	20	13	8.9	7.6	5.8	4.6
5	48	41	28	18	12	11	8.4	6.6
10	58	48	33	20	15	13	10	7.6
25	66	56	38	25	18	16	13	9.7
50	76	64	43	28	21	19	15	12
100	81	69	48	30	23	20	17	12

Table 4-5

Rainfall - Intensity Data (mm/hr), Areas With 450 mm to 550 mm Annual Rainfall

Recurrence Interval (years)	**Duration**							
	10 min	15 min	30 min	1 hr	2 hrs	3 hrs	6 hrs	10 hrs
2	43	36	25	17	11	9.4	7.4	5.6
5	58	48	33	22	15	13	10	8.4
10	71	61	41	26	19	16	13	9.7
25	81	69	48	30	23	20	16	13
50	94	79	53	36	23	23	19	15
100	102	86	58	38	29	25	20	16

Table 4-6

Rainfall - Intensity Data (mm/hr), Areas With 550 mm to 700 mm Annual Rainfall

Recurrence Interval (years)	**Duration**							
	10 min	15 min	30 min	1 hr	2 hrs	3 hrs	6 hrs	10 hrs
2	53	46	30	19	14	12	9.1	7.1
5	74	64	43	27	19	17	13	10
10	91	76	53	33	23	21	16	12
25	102	89	61	38	28	25	20	15
50	117	99	66	43	33	29	23	18
100	127	109	74	47	35	31	25	19

4.1.4 Example Problem

A sample basin has been selected to illustrate the application of the Rational Method in the San Luis Obispo Watershed. The sample basin is located west of Broad Street near Orcutt Road, south of Downtown San Luis Obispo. The City of San Luis Obispo general plan shows a mix of residential, open space, and industrial land use at general plan build out. **Figure 4-3** illustrates the basin and the soil, general plan land use, and slope characteristics of the basin. The following example computes flow at the outlet of the basin assuming general plan build-out land use conditions and existing channel conditions.

The composite runoff coefficient for the basin is computed using the area of each unique combination of land use, soil hydrologic group, and slope range in the basin. The total area of each combination has been tabulated in **Table 4-7**. The composite runoff coefficient is computed by assigning a runoff coefficient to each landuse/soil/slope combination, multiplying each respective coefficient by the total area represented by each combination, summing this product for all combinations, and dividing the sum by the total basin area.

The Time of Concentration is computed by defining the flow path from the most remote location in the watershed to the basin outlet, splitting this path into several segments, and computing the travel time in each segment according to the appropriate method (i.e. overland flow, shallow concentrated flow, or channel flow). This computation is illustrated in **Table 4-8**.

Table 4-9 illustrates the drainage calculations for the basin for the 2-year, 10-year, and 100-year recurrence interval events. C and T_c are as computed in **Table 4-7** and **Table 4-8**, respectively. Annual precipitation is taken from **Figure 4-2**, and the rainfall intensities are taken from the appropriate table (**Table 4-4, 4-5, or 4-6** depending on annual precipitation). The rainfall intensity for the time period T_c, i_{Tc}, is linearly interpolated between the nearest tabulated values (in this case the 15-minute and 30-minute values). C_a is taken from **Table 4-2**, and Q is computed according to **Equation 1**.

Table 4-7

Example Composite Runoff Coefficient Computation

	Area (m^2)	Soil Grp	Slope (%)	Land Use	C	C*Area
	300	D	<2	Rangeland	0.4	120
	15500	D	2-10	Rangeland	0.45	6975
	135200	D	>10	Rangeland	0.5	67600
	900	D	<2	1000 m^2 res	0.4	360
	12200	D	2-10	1000 m^2 res	0.5	6100
	2000	D	>10	1000 m^2 res	0.6	1200
	13500	D	<2	< 600 m^2 res	0.5	6750
	67300	D	2-10	< 600 m^2 res	0.6	40380
	33600	D	>10	< 600 m^2 res	0.65	21840
	7500	C	<2	Industrial	0.7	5250
	17300	C	2-10	Industrial	0.75	12975
	1700	C	>10	Industrial	0.8	1360
	300	C	2-10	1000 m^2 res	0.4	120
	2100	C	<2	< 600 m^2 res	0.45	945
	15600	C	2-10	< 600 m^2 res	0.5	7800
	2300	C	>10	< 600 m^2 res	0.6	1380
Total	**327300**				**Total**	**181155**
					Composite = 181155 / 327300 =	**0.55**

Table 4-8

Example Time of Concentration Computation

Segment	1	2	3	4	5
Type of Flow	Overland	Shallow Conc.	Shallow Conc.	Channel	Channel
Length L(m)	50	130	170	540	300
Upper Elevation (m)	181	164	106	89	67
Lower Elevation (m)	164	106	89	67	61
Watercourse Slope S	0.34	0.45	0.10	0.04	0.02
Watercourse Slope in % S_p	34	45	10	4	2
Watercourse n	n/a	n/a	n/a	0.03	0.045
Approx Channel top width (m)	n/a	n/a	n/a	1.5	3
Approx Channel Depth (m)	n/a	n/a	n/a	0.5	1
Hydraulic Radius R (m)	n/a	n/a	n/a	0.30	0.60
Interception Coefficient k	n/a	0.619	0.491	n/a	n/a
Equation to Compute Velocity	n/a	Equation 3	Equation 3	Equation 5	Equation 5
Velocity (m/s)	n/a	4.1	1.6	3.0	2.2
Method to Compute Time	Figure 4-1	Equation 4	Equation 4	Equation 4	Equation 4
Time (minutes)	9	0.5	1.8	3.0	2.2

Total T_c = 16.6 min

Table 4-9

Example Rational Method Runoff Rate Computation

Recurrence Interval	Area (hectares)	C	T_c (min)	Annual Precip (mm)	$i_{15\ min}$ (mm/hr)	$i_{30\ min}$ (mm/hr)	i_{Tc} (mm/hr)	C_a	Q (m^3/s)
2-year	32.73	0.55	16.6	500	36	25	35	1	1.75
10-year	32.73	0.55	16.6	500	61	41	59	1	2.95
100-year	32.73	0.55	16.6	500	86	58	83	1.25	5.19

4.1.5 Use of SLO/Zone 9 Hydrology Model for Catchment Areas Greater than 40 Hectares (100 acres)

A detailed numerical computer hydrology model was developed as part of the SLO Waterway Management Plan (the SLO/Zone 9 hydrology model). This model uses the Corps of Engineers runoff hydrograph method **HEC-HMS** that converts precipitation excess to basin runoff and channel discharge.

The SLO/Zone 9 model shall be used for all hydrologic calculations in the SLO Watershed for drainage facilities with more than 40 hectares (100 acres) of contributing watershed area. In addition, the SLO/ Zone 9 model shall be used in all City and County required or sponsored Area Plans, Specific Plans, Master Plans including Drainage Master Plans and Development Master Plans.

The SLO/Zone 9 hydrology model shall be used as a design aid for calculating flow in open channels with catchments over 40 hectares (100-acres) and in the design of all hydraulic and drainage structures in such catchments including:

- Open channels
- Bridges
- Culverts associated with such open channels
- Flood control
- Stormwater detention basins

A copy of the latest /updated version of the SLO/Zone 9 model, including model documentation can be obtained from the City Engineering Department for the cost in time and materials to reproduce the model, as determined by the City Engineer. The project proponent or design engineer will be responsible for making changes and revisions to the model, consistent with the modeling approach, and with the approval of the City and/or County Public Works Director. Procedures for updating the HEC-HMS model should be consistent with those outlined in the Hydrology and Hydraulics section of the San Luis Obispo Waterway Management Plan. Generally, there should be no need to develop new precipitation data; as precipitation already developed for the Zone 9 model characterizes the whole basin for a design event. The model parameters likely requiring modification includes sub-basin delineation and sub-basin parameters such as run-off curve numbers and lag time. The original GIS data used to generate the model are available from the City. The project proponent will supply a copy of the updated model to the City and County who will maintain the model in its most current configuration.

At the option of the design engineer, and with the written approval of the City or County Public Works Director, a new hydrologic computer model of a proposed project area catchment can be constructed.

4.1.6 Hydrology Report

Submittal Requirements:

1. Watershed Map and Sub-basin Delineation

   These should be drafted on a USGS 7.5 minute quadrangle or larger scale topographic map. The map should show all points of flow concentration and sub-basins, and should utilize a numbering system for these that is consistent with that used in the drainage calculations or computer model.
2. Peak flow rates at each point of concentration

   Peak flow rates should be computed for the 2-year, 10-year, 25-year, and 100-year precipitation event.
3. Flow hydrographs–for catchments over 40 hectares (100-acres) only.
4. Narrative and supporting assumptions such as runoff coefficients, times of concentration or lag times, channel routing assumptions, etc.
5. HEC-HMS computer model files on CD or other storage media–for catchments over 40 hectares (100 acres) only.

4.2 Open Channel Hydraulic Analysis

4.2.1 General

This section specifies the requirements for hydraulic analysis to be performed along open channels within the San Luis Obispo Creek watershed. Standard engineering analysis techniques should be sufficient for most closed-conduit problems within the San Luis Obispo Creek Watershed. The reader is referred to the Federal Highway Administration (FHWA) ***Hydraulic Engineering Circular No. 22, Urban Drainage Design Manual and Caltrans***, for additional technical closed-conduit information. Hydraulic design for open channels should follow the procedures as outlined in U.S. Army Corps of Engineers, ***Hydraulic Design of Flood Control Channels, 1993, EM-1110-2-1601***, or USDA Soil Conservation Service, ***1977, Design of Open Channels, T.R. No. 25.*** Policies for closed conduit design are listed in **Section 7.0** of this drainage manual.

Hydraulic analysis requirements for open channels within the San Luis Obispo Creek Watershed vary based on stream classification (see **Section 5-2** of this manual). Most Major and Secondary Waterways (see **Section 5.2**) within the watershed have already been modeled hydraulically as part of the Waterway Management Plan using HEC-RAS, the U.S. Army Corps of Engineers one-dimensional, steady flow backwater model. The existing models along these reaches should be used as a starting point for analysis. For Major or Secondary waterways not covered by the existing Waterways Management Plan HEC-RAS model, a new HEC-RAS model should be developed. For minor waterways and closed conduits, a HEC-RAS model is generally not required, but hydraulic information should still be developed assuming normal depth.

4.2.2 Hydraulic Analysis of Projects on Major and Secondary Waterways

Hydraulic Analysis For Projects in Reaches Covered By Existing SLO/ Zone 9 Hydraulic Model

The existing Zone 9 HEC-RAS model covers all of SLO Creek below Cuesta Park, and portions of Stenner, Prefumo, Brizziolari, and the East Fork of San Luis Obispo Creek. The SLO/Zone 9 HEC-RAS hydraulic model and model documentation is available from the City Engineer for the time and costs of reproduction. The SLO/Zone 9 hydraulic model shall be used for calculating floodwater surface elevations, velocities and shearing forces, and in completing floodplain determinations, for all Major and Secondary Waterways (see **Section 5.2**) covered by the model. The model shall also be used in the design of all hydraulic and drainage structures including:

- Open channels
- Bridges
- Culverts associated with such open channels
- Flood control
- Stormwater detention basins

At the option of the design engineer, and with the written approval of the City Engineer or County Public Works Director, a new hydraulic model of a proposed project stream reach can be constructed. However, the model for major and secondary channels must be a backwater model and must use the water surface elevations taken from the Zone 9 HEC-RAS model as downstream boundary conditions.

The Zone 9 hydraulic model was constructed using widely spaced cross-sections (every 50-150 meters) so it may be advisable to survey in some new cross-sections and add these to the channel model to create a more localized and accurate model of the project site. Cross-section spacings of 15 meters are recommended for design hydraulic analysis.

4.2.3 Hydraulic Analysis of Major and Secondary Waterways Not Covered by Existing SLO/Zone 9 HEC-RAS Hydraulic Model

The existing SLO/Zone 9 HEC-RAS hydraulic model does not cover all of the major and secondary waterways within the SLO Creek watershed (Section 5.2). In addition, certain secondary waterways covered by this Design Manual do not have detailed FEMA floodplain maps available. The applicant's civil engineer is responsible for the collection and analysis of all information with regard to flooding and channel hydraulics in these areas. This information shall include a description of past flooding, including dates of previous flood events, water depths, etc. The required hydraulic model for analysis shall be the U.S. Army Corps of Engineers HEC-RAS computer model. However, the City Engineer or County Public Works Director may approve other methods in certain situations, such as normal depth computation. Generally, a HEC-RAS model should be developed unless the reach in question is relatively short (less than 30m (100 ft) in length) is over 300m (1,000ft) upstream of any significant downstream constrictions such as bridges or culverts, and is not subject to significant overbank flooding.

A field study shall be made by the applicant's civil engineer to determine the hydraulic conditions of the proposed project area, including type and number of existing drainage and hydraulic structures that could affect flooding, proposed locations of cross-sections, conditions of the channel bank and channel bed, the nature of the existing vegetation, and other parameters such as roughness values which are necessary to complete the hydraulic analysis.

Existing Conditions cross-sections to be used in the hydraulic model shall be obtained by field surveying, and can be supplemented with topographic information obtained from aerial surveys. The elevation datum of all of the information used in the hydraulic analysis must use the NAVD 88 datum to maintain consistency with the Zone 9 HEC-RAS hydraulic model. Where possible, horizontal coordinates for channel cross-sections should use the City Coordinate System (NAD 83, CA Zone 5).

4.2.4 Hydraulic Analysis of Minor Waterways and Closed Conduits

The design engineer may use a non-backwater or normal depth hydraulic model for most minor waterways and closed conduits, subject to approval by the City Engineer or County Public Works Director. Use of a backwater computer model such as the Zone 9 hydraulic model will normally not be required for these situations, although they may be used at the discretion of the design engineer, or as required by the City or County.

4.2.5 Special Circumstances

In some cases the SLO/Zone 9 or applicant-constructed HEC-RAS model alone may not be sufficient for completing the required hydraulic analysis. This may be the case where sediment transport, complex openings at bridges, weirs, or culverts, two dimensional or unsteady flow, or other unique hydraulic circumstances affect the use and accuracy of the model. The applicants' engineer in consultation with the City or County will determine this. In these cases the applicant shall obtain the approval of the City or County for other methods proposed for hydraulic analysis.

4.2.6 Submittal Requirements

The following data should be the result of a hydraulic analysis for any stream type within the watershed. Results should be computed for the 2, 10, 25 and 100-year flow events, and should be computed for both pre and post project conditions.

- Water surface elevations through project reach;
- Velocity;
- Shear stress (both cross-section average and corrected for bend curvature, where applicable);
- Floodplain delineation (for projects where floodplain extent is in question);
- Floodplain storage volume (for projects where fill is proposed within a floodplain), and:
- Supporting assumptions such as channel roughness values, cross-section geometry, etc.

SECTION 5.0

OPEN CHANNEL ANALYSIS AND DESIGN REQUIREMENTS

5.1 Channel Classification and Definitions

An open channel or waterway collects runoff from its contributing area and conveys it to another point, usually a lower order channel, and ultimately to the Pacific Ocean at Avila Beach. This section presents the management classification system for the waterways in the SLO creek watershed along with criteria that shall be used for determining the future management classification for the stream. It also provides guidance to the opportunities and constraints of changing the management classification of a stream by implementing channel conveyance enhancement, stabilization and restoration and enhancement activities. Not all of the criteria presented need be satisfied.

Waterways or channels, which fall under the jurisdiction of this Design Manual, shall be classified as defined below. A waterway may be subdivided into reaches, each with a unique and different classification; however for practical management purposes each reach shall be of a length which is reasonable for the classification designated. If the consulting engineer disagrees with a stream categorization, it is his / her responsibility to submit any documentation or rationale needed to the City or County for final classification. Bridges, short lengths of culverts, or individual structural bank protection segments are not to be considered as separate channel reaches for classification purposes.

There are several types of channels, which occur in the SLO Creek watershed. Engineering and planning studies may indicate that these channels may need to be altered from time to time to meet community needs or specific project objectives. Such alterations can be completed, subject to CEQA and/or NEPA review, public hearings, and appropriate government body review and approval. Channel classifications and design restrictions on channel modifications are described in the following section:

- ***Figure 5-1*** shows the channel classifications by channel reach for the major streams within the SLO watershed. It is the responsibility of the design engineer to propose a channel classification for those creek reaches and streams not classified. The classification is subject to the approval of the City Engineer or County Public Works Director.
- ***Natural Channels***: A natural channel is defined as an existing stream or waterway, which has been created by natural hydrologic and geomorphic processes. It has had a minimum of channel modifications in terms of widening and channel lining, and follows more or less the historic alignment. Natural Channels typically have a compound or multi-stage channel morphology, with areas of near vertical slopes and in-channel benches located at the approximate two-year flow line. They typically have channel bottom aquatic diversity such as pools and riffles, and often have a distinctive meandering pattern.

  Stream reaches classified as Natural Channel segments are limited in occurrence along the main stem of SLO Creek, but are more common along tributary streams. In addition, many of the natural channel reaches within the SLO watershed are currently unstable and/or lack adequate conveyance capacity to contain the design flows designated in ***Section 5.2***. Where detailed hydraulic and geomorphic analysis indicates this to be the case, a **Natural Channel** may be modified to create a **Constructed Natural Channel** as described in this section, and following the design guidelines presented in ***Section 5.3.*** This is subject to further project specific analysis and CEQA review.

*The criterion which makes a channel suitable for continued management and maintenance as a **Natural Channel** include the following:*

- *Part of an existing riparian corridor*
- *Nearby wetlands or other important habitat areas*
- *Immediately adjacent areas are largely undeveloped*
- *High value existing natural conditions*
- *Adequate channel capacity to meet flood management objectives for reach per **Waterway Management Plan***
- *Channel banks mostly stable*

- ***Altered Naturalized Channels***. An **Altered Naturalized Channel** has many of the attributes of a Natural Channel in terms of vegetation and aquatic features, but has experienced some prior modifications and is not geomorphically stable due to past disturbances and channel alterations. These channels will therefore require a higher degree of maintenance and management than Natural Channels.

  Most of the middle and lower channel reaches along the main stem of SLO Creek (especially below Los Osos Valley Road Bridge) have been straightened, realigned, partially lined with rock rip rap and broken concrete slabs and otherwise altered associated with construction or widening of Highway 101 during the late 1940's, and with historic development of the City of San Luis Obispo. The straightening of the channel increased the channel slope and has resulted in erosion of the channel bed and lateral migration of the channel (bank erosion), particularly during periods of unusually high creek flows. Despite this instability, most of the historically altered creek reaches have become vegetated or naturalized with willows and other native and non-native tree canopy cover, have achieved important stream bottom aquatic structure and provide important wildlife and aquatic habitat.

  The criteria, which make a channel suitable for continued management and maintenance as an Altered Naturalized Channel, include the following:

  - *Part of an existing riparian corridor*
  - *Nearby wetlands or other important habitat areas*
  - *Adjacent areas are undeveloped*
  - *High value existing natural conditions*
  - *Adequate channel capacity to meet flood management objectives of **Waterway Management Plan***
  - Channel highly unstable

- ***Modified Channels***: A **Modified Channel** is defined as a drainage facility designed for the principle purpose of collecting and conveying runoff in an efficient manner. It lacks many of the attributes of a **Natural** or **Altered Naturalized Channel** (in terms of having compound channel morphology, such as an in-channel terrace or bench located at the two year flow line), often have a simple, relatively straight platform, and lack channel bottom aquatic diversity. Modified Channels are often lined with rock rip-rap, gabions, or other means of providing erosion protection from flowing water, and are not stable.

Construction of new Modified Channels should be avoided within the SLO watershed, and existing Modified Channels are to be reconstructed as Constructed Natural Channels wherever feasible, in association with new development or redevelopment projects, or as mitigation for upstream and downstream hydraulic/geomorphic impacts as required by ***Section3.4.***

The criteria, which makes a channel suitable for continued management and maintenance as a Modified Channel, includes the following:

- *Armored with concrete, grouted rock, or other hard, inflexible lining*
- *Not part of an existing continuous, riparian corridor; habitat is fragmented*
- *Very low biological value and low potential for enhancement/restoration without significant modification*
- *Little room at top of bank; top of bank urbanized*
- *Grossly inadequate channel capacity to meet Waterway Management Plans Design Flow objectives*, *if altered.*

- ***Constructed Natural Channel***. A **Constructed Natural Channel** (also sometimes called a Landscaped, Constructed channel - see ***Figure 5-2***) may be constructed from an Altered Naturalized or Modified Channel, (but not usually a Natural Channel) where it has been shown that the channel lacks the Design Flow conveyance capacity, is geomorphically unstable, or reconstruction is necessary to meet approval mitigation requirements. The waterways are to be designed in accordance with all of the provisions of these design criteria applicable to Constructed Natural Channels (see ***Section 5.3***). Typically, this will include construction of a compound channel utilizing an in-channel bench or terrace whenever feasible, considerations of stable channel planform geometry, use of setbacks and buffer strips at top of bank, planting using native plants, slope stabilization using biotechnical erosion control methods, and incorporation of aquatic habitat enhancement elements within the stream bottom, such as boulders and root wads.

  The criteria, which makes a channel suitable for management and maintenance as a Constructed Natural Channel includes the following:

  - *Not extensively armored with concrete, grouted rock, or other hard, inflexible lining*
  - *High potential for enhancement/restoration*
  - *Adequate room at top of bank for alteration and management*
  - *Existing channel instability or has inadequate capacity to meet flood conveyance objectives and requires substantial modification.*

- ***Closed Conduits***. Closed conduits consist of pipe flow. Projects whose design discharge may reasonably be placed in a 1,220 mm (48 inches) or smaller pipe shall be placed underground, except for existing natural waterways, constructed natural waterways, and allowable gutter and roadside ditches. Generally waterways, which fall under the jurisdiction of the U.S. Army Corps of Engineers, cannot be undergrounded.

5.2 Channel Design Flow Requirements

For purposes of designating Design Flows, required design capacities and design requirements, the system of creeks and waterways in the SLO watershed is divided into major, secondary, and minor waterways. All existing and proposed conveyance systems shall be analyzed and designed using the peak flows for the hydrographs developed per the procedures described in ***Section 4.0*** to meet the following design capacities:

Major Waterways within the City of SLO**;** For Major Waterways within the City of San Luis Obispo, Design Flows are designated for the following creeks:

1. San Luis Obispo Creek above confluence with Stenner Creek-40 year (*1)
2. San Luis Obispo Creek below confluence with Stenner Creek to Madonna Road -20 year
3. San Luis Obispo Creek from Madonna Road to Prado Road - 50 year
4. San Luis Obispo Creek from Prado Road to confluence with Prefumo Creek - 100-year
5. San Luis Obispo Creek from Prefumo Creek confluence to City Urban Reserve Line - 100 year
6. San Luis Obispo Creek below City Urban Reserve Line - Maintain existing capacity (approximately 10-year event for much of reach.
7. Stenner Creek from SLO Creek to Chorro Street - 50 year
8. Stenner Creek from Chorro Street to Urban Reserve Line - 100 year
9. Prefumo Creek within Urban Reserve Line - 100 year (*2)
10. Old Garden Creek within Urban Reserve Line - 25 year
11. East Fork from SLO Creek to Broad Street (*3)

(*1) 100-year protection can be provided with the Cuesta Park Detention Enhancement project
(*2) Prefumo Creek currently has capacity for more than the 50-year flow, except where it enters SLO Creek at Los Osos Valley Road. At that location, highwater in SLO Creek causes backwater flooding of the highway at about a 15-year event. 100-year protection can be achieved by improvements to the culverts at this location.
(*3) East Fork of San Luis Obispo Creek is included in the Airport Area Specific Plan. Standards and plans for flood management are included in the plan and related environmental documents.

Final adoption of the Design Standards in Section 5.2 is dependent upon City Council and County Board of Supervisors adoption of the Waterway Management Plan and an evaluation and certification of the environmental impacts associated with implementing the Plan as contained in the project Environmental Impact Report.

Other Major Waterways -not named above and within the City Urban Reserve Line or, outside of the City that have a drainage area of over **10 km^2 (4 mi^2)** (four square miles) shall be designed for an average recurrence interval of **25-years** with 0.6 m (2 ft) of freeboard, and shall have sufficient capacity for a **50-year** design discharge either by alternate surface routes (such as shallow street flow) or be contained within the channel without freeboard.

Secondary Waterways have a drainage area of between **2.6 km^2 and 10 km^2 (1 and 4 mi^2)** and shall be designed for a storm recurrence interval of **25 years**, with 0.3 m (1 ft) of freeboard.

Minor Waterways have a drainage area of less than **2.6 km^2 (1 mi^2)** and shall be designed at minimum of a storm recurrence interval of **10 years**, with 0.3 m (1 ft) of freeboard.

A given waterway, therefore, can be classified both as to its existing and planned design condition per ***Section 5.1***, and for its Design Flow capacity. A waterway may be classed as minor in its upper reaches, then changed to the secondary classification at a point where the drainage area exceeds **2.6 km^2 (1 mi^2)** and changed again to the major classification at a point where the drainage areas exceeds **10 km^2 (4 mi^2)**, or a named reach as outlined above.

5.3 Open Channel Design Criteria for Major and Secondary Waterways

Once the design discharge is computed and the appropriate level of protection, or channel design flow capacity is determined (per ***Section 5.2***), a channel conveyance system to meet these requirements can be designed. Open Channel design references include *Federal Highway Administration River Engineering for Highway Ehancements HDS6* (FHWA, 2001), *The Design of Open Channels*, *Technical Release 25* (USDA, SC5, 1977), and *Hydraulic Design of Flood Control Channels, EM 1110-2* (U.S. Army Corps of Engineers, 1991). A conveyance system includes all portions of the surface water system, both natural and man-made, that transport or convey stormwater and surface water runoff, and any diverted water or intercepted shallow groundwater flow. The purpose of the conveyance system shall be to drain the surface water from properties up to a specific design flow, so as to provide protection to building occupants, the property, and the environment.

- For open channel flow, the channel section will be sized to provide adequate capacity for the design flows while controlling erosion and maintaining channel stability, habitat protection, and where possible, providing additional enhancement.
- For closed conduit flow (pipe flow) the system shall be designed to maximize hydraulic efficiency and minimize maintenance and repair by utilizing proper materials and construction methods, slope, and size.
- All constructed conveyance systems are to be designed to emulate a natural conveyance system to the maximum extent feasible.
- Inflow and outflow should occur at the natural drainage points as determined by topography and the historic or existing drainage patterns, and channel planform and grade should emulate nearby natural drainage systems.

5.3.1 Constructed Natural Channel Design

Natural channels are shaped by the forces of flowing water and erosional processes acting on the banks and adjacent floodplain areas. Nearly all-natural channels within a watershed have similar characteristic shapes and cross-sections, which relate to the flow-frequency characteristics of the watershed and the climate geology, soils and vegetation of the watershed. In natural channels, specific vegetation zones are associated with various positions on the channel bank (upper bank, bank top, mid channel terrace, toe, etc.).

- ***Constructed*** *or* ***Modified Channels*** typically have much less complex shapes than natural channels, and are often linear or curvilinear, are typically even or uniformly sloped, and often trapezoidal in shape. The effect of this simplicity is to eliminate the relationship between channel shape and flow, thus also eliminating characteristic natural vegetation zones and flow complexity important to aquatic habitat. Although this design maximizes hydraulic flow capacity in the cross section, it often requires extensive maintenance to maintain the design capacity, due to siltation, bank erosion, and growth of channel bottom vegetation. The flattened bank slopes of the constructed or engineered channel also makes shading of the channel more difficult, and often eliminates the occurrence of undercut banks, and associated pools which provide important fish habitat. This design-influenced condition is to be avoided in the San Luis Obispo Watershed:

- Where detailed hydraulic studies indicate the need to modify or restore an existing **Altered Naturalized Channel** to improve flood conveyance, a **Constructed Natural Channel** design shall be used.
- Constructed Natural Channels, which emulate the form and function of natural channels in design, are to be a part of the City's and County's open space and flood management system, which place an equally high value on preserving natural systems and enhancing wildlife and fisheries habitat.
- The stability and maintenance requirements of the **Constructed Natural Channel** shall be considered in the design.
- The design shall typically include a two-stage or compound channel with a separate low flow channel within the overall flood channel.
- The design shall include provisions for emulating natural channel cross-section, as well as natural channel planform shape and bedform or channel bottom features, such as pools and riffles.

5.3.1.1 Cross-Section Design

Floodplain as used in this Design Manual refers to the generally flat area immediately adjacent to a channel, which is periodically flooded. Sometimes a specific recurrence interval is used to define the floodplain, such as the 2- year, 10-year, 25-year or 100-year floodplain.

The main channel occurs below the floodplain and is capable of carrying the "bankfull discharge" which typically recurs at the approximately 2-year peak flow along a natural channel. Often the 2- year floodplain occurs as an easily recognizable but intermittent in-channel bench or terrace along the stream course, located about 1/3 to ½ of the way up the channel bank in the SLO Creek Watershed.

Due to channel incision, channel modification and widening, and floodplain fill, the flood recurrence interval for flooding which escapes the banks now ranges from less than 10 years to over 50 years along portions of SLO and Stenner Creeks upstream of Los Osos Valley Road (LOVR).

The low-flow channel is typically well defined along most of the creeks in the SLO Creek watershed, although it has not been clearly associated with any specific recurrence interval peak flow or flow duration. It can be considered as the lowest elevation part of the channel, including the channel thalweg, and for design purposes shall be assumed as the portion of the channel that conveys the early summer (June) flow. The channel thalweg is defined as the line following the bed of a stream or river. Each of these subareas of the channel cross-section, the low flow channel and thalweg, in-channel bench or 2-year floodplain, main channel, and overbank floodplain plays a different role and must be considered in designing a **Constructed Natural Channel**. ***Figure 5-2*** shows a schematic channel cross-section of a **Constructed Natural Channel** with a floodplain terrace.

The following guidelines should be used in designing a **Constructed Natural Channel**:

- The adjacent lowest flood plain terrace shall receive flow on the average of every 1.5 to 2.5 years.
- When designing natural channels a channel Mannings ‘n’ value of 0.050 for fully maintained channels and 0.075 for infrequently maintained channels shall typically be used.

5.3.1.2 Low-Flow Channel

- Unless the **Constructed Natural Channel** represents a relocation of the existing natural channel, normally channel modification work will occur above the low flow channel, and steps shall be taken to preserve, protect, and enhance where possible the low flow channel.
- Where it is necessary to relocate the low-flow channel in the new channel design, the low flow channel shall typically have a cross-sectional capacity calculated to be equal to ½ the depth of the 2-year peak flow depth. Low-flow channels shall be sized to carry summer time flows in a relatively confined space with a width: depth ratio typically less than 5. This limits the wetted area, reducing the potential for growth of vegetation in the channel bottom where it can have an impact on hydraulic capacity. The confined shape will also help to transport sediment through the system, reducing siltation. Minimum depth of the low flow channel shall be 0.75 m (2.5 feet), the maximum depth shall not exceed 2.4 m (8 ft). Shallow depths shall be preferred for smaller tributary streams.
- The low-flow channel should be graded into a natural meander pattern. Determination of precise parameters such as amplitude and wavelength of the meanders is variable. Upstream and downstream plan forms should be analyzed. For severely degraded stream reaches, similar reference creeks in other near-by watersheds may be used to determine appropriate meander patterns. Refer to ***Section 5.3.1.5*** “Channel Planform”.

5.3.1.3 In-Channel Bench or Floodplain Terrace

Flood conveyance capacity can be increased along certain reaches of SLO Creek by constructing an in-channel bench or terrace, artificially enlarging the floodplain. Generally only one side of the channel shall be disturbed, although the channel terrace can be moved from side to side to permit construction of a more complex and meandering section, and to selectively avoid areas of more sensitive stream-side features. The terrace shall typically be constructed above Ordinary High Water (OHW), and above the 2 or 2.5-year peak flow. If the floodplain is already at the 2-year flow, then the floodplain can be enlarged by excavation and grading and the soil cut placed elsewhere on the regulated floodplain, balancing cut and fill per the requirements of ***Section 3.0. Approval for enlarging the floodplain is subject to demonstration by detailed hydraulic analysis that the channel and floodplain modifications do not create undesirable effects upstream or downstream.***

5.3.1.4 Bank Slope

Normally bank slopes shall be designed at 2.5 Vertical to 1 Horizontal (2.5V:1H), unless geotechnical stability analysis indicates a different slope angle is possible. Impingement into the stream channel by the toe of the reconstructed channel slope is to be avoided to the maximum extent feasible. Bank steepness should be higher on the outside of a meander, and flatter on the inside of the curve, wherever practicable. This may require the use of retaining structure such as a live crib wall to provide the overhanging cover and shade at a channel bend.

5.3.1.5 Channel Planform

Channel planform refers to the shape of the channel as seen from overhead, or in plan view. Natural channels typically show a meandering pattern, with the channel looping back and forth across the valley bottom in an often regular and somewhat sinusoidal sequence. ***Figure 5-3*** shows a pool: riffle sequence and the location of point bars in a meandering natural channel illustrating the nomenclature used to describe channel planform features. This heterogeneity in the channel form and bed material creates beneficial aquatic habitat diversity. The meanders lengthen the channel relative to the distance traveled along the valley.

The degree of meander relative to main channel width tends to be the same for channels within a region that have similar watershed geology and climate, slopes, floodplain configuration, and bed material. Because the meanders and associated pools and riffles create habitat diversity, maintain channel storage, and are of a form that streams have adjusted to over time, it is desirable to replicate the natural channel meander configuration in planform in **Constructed Natural Channels**. This can be done by evaluating a natural channel section located upstream or downstream from the project area. Where a natural channel reference reach is not available for review, general channel geometric relationships can be utilized. Based on general information collected for the streams in the SLO Creek watershed, and from work on other streams in California, the following ratios are recommended:

- Radius of curvature=2.4 to 2.7 x bankfull channel width at 2-year peak flow (Q2)
- Meander length=10 to 14 times bankfull channel width at 2-year peak flow (Q2), average is 12 times bankfull width.
- Pool and riffle profiles are formed in erodible channels with an average spacing of 4 to 6 times bankfull width.

5.3.2 By-Pass Channels

If sufficient space is not available at top of bank to provide out-of-bank flood flow along the main channel and floodplain, and modification or disturbance of the main channel is precluded because of sensitive environmental features, another potentially acceptable design approach is to create a secondary overflow channel or depressed secondary floodplain that is separated from the main channel by a vegetated berm. The existing waterway would carry a portion of the flow, with the by-pass waterway carrying the remainder of the Design Flow. Schematic cross sections of two by-pass alternatives are shown in ***Figure 5-4.***

- The alignment of the by-pass should generally be parallel to the natural waterway. Both ends of the constructed by-pass and natural channel shall be designed in such a manner that upstream and downstream waterways will not be degraded by erosion, sedimentation, or other undesirable effects.

- Native vegetation shall be preserved and enhanced within the zone of separation, creating the vegetated berm. It may be necessary in some cases to add to the height of the natural berm to confine the design flow to the main channel and secondary flow to the by-pass area.

- The bottom or invert of the secondary channel and alternate floodplain shall be constructed above the elevation of the 2-year peak flow to avoid interception of low flow. The vegetated berm is also necessary to confine the 2-year flow to the main channel and to maintain sufficient channel forming flows within the primary channel to preserve its functions and values and provide sediment transport.

5.3.3 Modified Channels

This Design Manual recognizes that a **Constructed Natural Channel** may not be able to be built at some locations because of space constraints or unusual bank stability problems and erosive conditions. Certain geotechnical and geomorphic conditions may necessitate the use of hard channel linings, which generally preclude construction of a floodplain terrace. The design engineer shall submit a narrative to the City Engineer or County Public Works Director rationalizing the selection of a Modified Channel, or the use of hard channel lining for erosion protection. The following design criteria pertain to Modified Channels:

- Modified channels shall be designed to convey the appropriate recurrence interval Design Flow event as described in ***Section 5.2***.

- Freeboard shall be 0.3 meters (1 ft) above the design flow. A freeboard of 1.0 m (3.3 ft) is required beneath new bridges and utility crossings.

- Design channel bottom slopes shall be from 0.2 to 0.6 percent.

- Design side slopes shall be no steeper than 2:1 (two horizontal to one vertical [2H:1V]) for rock lined channels, and 2.5H:1V for earthen, grass lined or vegetated channels. Special designs are required for steeper slopes and must be approved by the City or County.

- Channel Cross Section may be parabolic or trapezoidal

- Alignment- Sharp curves shall not be used. Centerline curves shall not have a radius of less than twice the design flow top width, and will typically be 3 times the average channel width, or 10-meters (33-ft.), whichever is greater.

- Where a new low-flow channel or channel relocation is required, bottom width shall be 6 to 8 times depth of flow.

- Hydraulic Grade Line- The design hydraulic grade line, or water surface profile, shall be shown on all improvement plans for open channels. Supporting calculations and hydraulic model runs should be attached.

- Velocity restrictions for channels with varying soil materials and linings are provided in ***Table 5-1***.

TABLE 5-1

Permissible Velocities For Natural Material

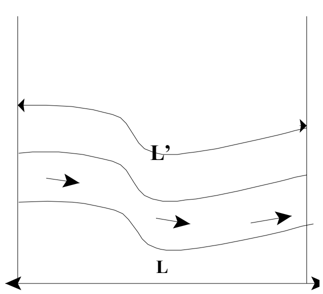
Soil Types	Permissible Velocity (meters/second)
Fine Sand (noncolloidal)	0.8 (3 ft./second)
Sandy Loam (noncolloidal)	0.8 (3 ft./second)
Silt Loam (noncolloidal)	0.2 (1 ft./second)
Ordinary Firm Loam	1.0 (3 ft./second)
Fine Gravel	1.5 (5 ft./ second)
Stiff Clay (very colloidal)	1.5 (5 ft./ second)
Graded, Loam to Cobbles (noncolloidal)	1.5 (5 ft./ second)
Alluvial Silts (noncolloidal)	1.0 (3 ft./second)
Alluvial Silts (colloidal)	1.5 (5 ft./ second)
Coarse Gravel (noncolloidal)	1.8 (6 ft./second)
Cobbles and Shingles	1.7 (5.5 ft./second)
Shales and Hard Pans	1.8 (6 ft./second)

REDUCTION IN PERMISSIBLE VELOCITY BASED ON SINUOSITY

Sinuosity	Percent Reduction in Permissible Velocity
Slight (1.0 to 1.2)	5%
Moderate (1.2 to 1.5)	13%
Very Sinuous (1.5 and greater)	22%

*Sinuosity - degree of curvature of channel

Source: American Society of Civil Engineers, 1985.



Manning's Roughness Values are provided in ***Table 5-2***. ***Table 5-3*** provides guidance on Manning values to use for managed natural areas along stream courses with various densities of vegetation. Roughness values corresponding to a mature creek system shall be used for design. ***Table 5-3*** can also be used to select plant spacings for restoration and enhancement planting, and for thinning vegetation for increased flood conveyance.

Values of the Roughness Coefficient "n"

Type of Channel & Description	**Mannings "n" (Normal)**
A. Constructed Channels	
a. Earth, straight and uniform	
1. Clean, recently completed	0.018
2. Gravel, uniform section, clean	0.025
3. With short grass, few weeds	0.027
b. Earth, winding and sluggish	
1. No vegetation	0.025
2. Grass, some weeds	0.030
3. Dense weeds or aquatic plants in deep channels	0.035
4. Earth bottom and rubble sides	0.030
5. Stony bottom and weedy banks	0.035
6. Cobble bottom and clean sides	0.040
c. Rock Lined	
1. Smooth and uniform	0.035
2. Jagged and irregular	0.040
d. Channels not maintained, weeds and brush uncut	
1. Dense weeds, high as flow depth	0.080
2. Clean bottom, brush on sides	0.050
3. Same, highest stage of flow	0.070
4. Dense brush, high stage	0.100
B. Natural Streams	
B-1 Minor streams (top width at flood stage <100 ft.)	
1. Clean, straight, full stage, no rifts or deep pools	0.030
2. Same as above, but more stones and weeds	0.035
3. Celan, winding, some pools and shoals	0.040
4. Same as above, but some weeds	0.040
5. Same as 4, but more stones	0.050
6. Sluggish reaches, weedy deep pools	0.070
7. Very weedy reaches, deep pools or floodways with heavy stand of timber and underbrush	0.100
B-1a Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages	
1. Bottom: gravel, cobbles and few boulders	0.040
2. Bottom: cobbles with large boulders	0.050
B-2 Floodplains	
a. Pasture, no brush	
1. Short grass	0.030
2. High grass	0.035
b. Cultivated areas	
1. No crop	0.030

Type of Channel & Description	Mannings "n" (Normal)
2. Mature row crops	0.035
3. Mature field crops	0.040
c. Brush	
1. Scattered brush, heavy weeks	0.050
2. Light brush and trees	0.060
3. Medium to dense brush	0.070
4. Heavy, dense brush	0.100
d. Trees	
1. Dense willows, straight	0.150
2. Cleared land with tree stumps, no sprouts	0.040
3. Same as above, but with heavy growth of sprouts	0.060
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.100
5. Same as above, but with flood stage reaching branches	0.12

Source: "Open Channel Hydraulics", V.T. Chow and King County Washington, Surface Water Drainage Manual, January 1990.

TABLE 5-3
Guide for Determining "n" Values
For Vegetation Management Classes

CLASS	DESCRIPTION (WHR* CLASS)	TYPICAL DENSITY TREES/ACRE	TYPICAL BASAL AREA/ CANOPY COVER	"n" VALUE*
1	Dense Thicket (Dense)	300-600+	BA > 100 Cover 80-100%	.091-.150
2	Closed Canopy(Dense)	200-400+	BA 50-100+ Cover 80-100%	.076-.090-managed .080-.150-unmanaged
3	Park-Like(Dense)	120-300	BA 30-50 Cover 60-79%	.060-.075-managed .071-.090-unmanaged
4	Moderately Dense (Moderate)	50-150	BA 20-30 Cover 40-59%	.046-.059-managed .050-.070-unmanaged
5	Savanna-Like (Open)	10-60	BA < 20 Cover 25-39%	.038-.045
6	Oak-Grassland (Sparse)	<10	BA < 10 Cover < 25%	.030-.037

* Note: Typically use the lower "n" value for the lower Basal Area (BA) or canopy cover range and the higher "n" value for the upper end of the class. Separate "n" values are given for managed stands, where selective thinning and limbing and removal of hazardous trees and downed woody debris has occurred. Consider also the extent of ground cover and shrubby vegetation. In extreme cases with dense ground cover and downed woody debris, increase "n" value by .05 to .10.

WHR = Wildlife Habitat Ranking

Source: Questa Engineering Corporation, 1995.

SECTION 6.0

ANALYSIS & DESIGN OF BANK STABILIZATION STRUCTURES

6.1 General

This section provides the required approach for the design and implementation of all public and private bank repair and bank protection projects within the San Luis Obispo watershed. Due to the great variability in conditions within the watershed, streambank erosion control and bank stability design is to be based on site-specific conditions, including:

- Site biological resource values;
- Physical conditions such as bed slope, channel roughness, location (inside or outside of channel bend), soil type and geotechnical stability requirements;
- Hydraulics, including flow velocity and shear forces, and;
- Characteristics of the channel and adjacent site including the available right-of-way, and what is located at top of bank that needs to be protected.

The general approach to be used in the SLO Creek watershed is sometimes referred to as the "Tractive Force" method, as outlined in ***Federal Highway Administration Manual HEC 15SI*** (Federal Highway Administration, 2000). This is available at http://www.fhwa.dot.gov/bridge/hydpub.htm. This method compares the shear stress or tractive forces acting on a site with the shear strength of bank soils and shear resistance of bank protection materials in selecting appropriate channel bank lining. Alternative methods of analysis, such as "Permissive Velocity" are subject to the approval of the City Engineer or County Public Works Director.

Emphasis shall also be placed by the design team on an assessment and understanding of the overall geomorphic stability of the stream reach where the project is located, especially with respect to channel bed conditions (i.e., reach is either stable, is aggrading sediment, or is degrading and eroding) and overall erosion and sediment transport dynamics.

6.2 Design Goals and Design Requirements

The goals of the design process are to insure selection, design, and construction of a project:

1. That is stable over the long term.
2. That is the least environmentally damaging and the "softest" approach possible.
3. That does not in turn create upstream or downstream flooding or induce other local stream instabilities.
4. That minimizes impacts to aquatic and riparian habitat and insures that all identified impacts are adequately mitigated, preferably onsite.

Detailed biological, geotechnical and geomorphic and hydraulic studies should be completed prior to design of large bank repair structures to insure that these goals are met.

As specified in **Section 3.6**, vegetative or Biotechnical slope repair and bank stabilization techniques will be the preferred approach in the San Luis Obispo Creek watershed. Where geomorphic, hydraulic, and geotechnical studies indicate that "hard" elements such as rock rip-rap or gabion baskets are required, vegetation must be included in the design in an "Integrated" project approach. Native plant revegetation of the bank top and adjacent bank slope areas, to the maximum extent feasible, is also to be an important component of a project. The type and density of vegetation will be dependent on the method of bank protection used and the physical properties of the stream where the repair is taking place.

In **Natural Channels** and where flow conveyance requirements are minimal and flow velocities are generally moderate, vegetative methods for stream bank repair are to be selected. In **Altered Natural Channels**, **Constructed Natural Channels**, or **Modified Channels** where the channel is used to convey flood flows, and where the flow requirements must be retained (such as for the 25-year flood), conveyance constraints will dictate a roughness maximum which, depending on the channel design, may limit the vegetation component of the design, and necessitate periodic vegetation management. Emphasis shall be placed on selection of appropriate Biotechnical and Integrated approaches, as outlined in **Section 3.6** of this Manual.

Streambank stabilization usually involves one or a combination of the following activities:

- Regrading and revegetating the streambanks to eliminate overhanging banks and create a more stable slope;
- Deflecting erosional water flow away from vulnerable sites;
- Reducing the steepness of the channel bed through installation of grade stabilization structures;
- Altering the geometry of the channel to influence flow velocities and sediment deposition;
- Diverting a portion of the higher flow into a secondary or by-pass channel;
- Armoring or protecting the bank to control erosion, particularly at the toe of slope.

Armoring the bank takes a variety of forms, some of them structural, but most capable of incorporating revegetation as an essential component. The optimum, or preferred, treatment at any location along a creek is to be a function of:

- Existing bank conditions;
- Proximity of structures;
- Cost; and,
- Environmental impacts.

The least environmental damaging solution feasible must be selected.

Determination of the appropriate bank erosion control method is to be based on an inspection of the stream upstream and downstream of a project site to determine if there is an identifiable cause of the erosion. In some cases, the cause of erosion is obvious, such as a blockage (e.g., downed tree), or weak stream banks of silt or gravel. In other cases, a further inspection is necessary to determine if flows are being directed toward the bank from a source upstream, or whether the channel (bed) is down cutting. These factors can affect selection of the bank protection technique to be implemented.

6.3 Design References

The designer is referred to the following resources for a more detailed description of stream geomorphic assessment techniques and approaches to biotechnical streambank stabilization design. Those printed in bold face type are available for review at the City of San Luis Obispo Public Works Department.

California Department of Fish & Game, California Salmonid Stream Restoration Manual (http://ww.dfg.ca.gov/fishing/manual3.pdf)

Flossi, G., S. Downie, J. Hupelain, M. Bird, R. Cowy, and B. Collins. California Salmanoid Stream Habitat Restoration Manual. California Department of Fish & Game, Inland Fisheries Division. Sacramento, California (February, 1998).

Gray, Donald H. and Andrew T. Leiser, (1982), Biotechnical Slope Protection and Erosion Control, Vom Nostrand Reinhold Company, New York.

Kondolf, Matt and H. Pigar, (August, 2002), Methods in Fluvial Geomorphology; John Wiley and Sons.

King Co. Department of Public Works, (June, 1993), Guidelines for Bank Stabilization Projects in the Riverine Environments of King County, Seattle, Washington.

National Marine fisheries Service, NMFS Southwest Region (2000), *Guidelines for Salmonid Passage at Stream Crossing*. http://swr.vcsd.edu/hcd/fdscg.pdf.

Natural Resources Conservation Service (NRCS), (December, 1996), Streambank and Shoreline Protection, Engineering Field Handbook, Chapter 16, Washington D.C.

Rosgen, D., Applied River Morphology, (1996), Wildland Hydrology, Pagosa Springs, Colorado.

Schiechtl, H.M. and Stern, R.," Water Bio Engineering Techniques for Watercourse, Bank, and Shoreline Protection", Blackwell Science, Cambridge, Massachuset, 1996, p.186.

U.S. Army Corps of Engineers. (April, 1997), Bioengineering for Streambank Erosion Control, 90p., Vicksburg, MS.

U.S. Department of Transportation. (1985), Streambank Stabilization Measures for Highway Engineers, National Technical Information Service PB-187986, Springfield, Virginia.

U.S. Department of Transportation. (2000), Design of Roadside Channels with Flexible Linings, HEC-15, Federal Highway Administration Number IF-00-022, Washington.
Available online at http://www.fhwa.dot.gov/bridge/hydpub.htm

U.S. Department of Transportation. (2001), Stream Stability at Highway Structures, HEC-20, Federal Highway Administration Number NH-01-002, Washington.

U.S. Government Interagency Task Force 1998, Stream Corridor Restoration - Principles, Process, Practices. This manual was produced by a consortium of Federal Agencies and includes

background information on important hydrologic, geomorphic and biological principles. Available in hard copy or CD. http//:www.ntis.gov/product/stream-corridor.htm

Veri-Tech, Inc. (1999),Streambank Stabilization Handbook (Corps of Engineers developed the handbook - in electronic form only: www.veritechinc.com.

Two reference sources for assistance in the preparation of Bioengineering Plans and Specifications are available on the world-wide web:

2. Washington Department of Transportation (WDOT): www.wsdot.wa-gov/eesc/cae/design/SBwebsite

3. USDA Natural Resources Conservation Service: www.ncss.org/eda/html

A private vendor, Salix Applied Earthcare, a Natural Resource Consulting Firm, in Redding, California, has also prepared a compendium of Biotechnical Soil Stabilization Solutions on CD, "BioDraw" which are available for purchase. Neither the City nor County require the use of, or specifically endorse "BioDraw".

6.4 Project Permitting & Approval Process

Obtaining all necessary regulatory approval for bank stabilization work near or within streams in the San Luis Obispo Creek watershed has historically been a time consuming and often confusing process. By law, a project usually requires approval from a number of agencies, as discussed in ***Section 6.5.2***, Step 4. This Design Manual is intended to help simplify this process.

While agencies with jurisdiction over stream projects will not waive their responsibility to review project plans before construction, the strategy employed in this manual and the companion Stream Maintenance and Management Program (**SMMP**) for streamlining the review process involves coordination between the City/County (depending on project location) and all regulatory agencies, with the goal that an applicant would submit one design study and permit application to the City/County for review, rather than a separate application for each agency. The City/County, after reviewing the project for consistency with the guidelines described in this Section, would add the project to an annual Master List of projects, termed the **Annual Work Plan (AWP)**, to submit at one time, by July 1, to all the agencies for approval. Since the City/County would already have provided professional design review, it is unlikely (though not impossible) that the project would not receive approval. The goal is for the AWP to receive approval for construction on or by August 15 of any given year. The City or County will reserve the right to request modifications to privately proposed projects, or reject those that they do not consider as appropriate and consistent with this Design Manual or the Stream Maintenance and Management Program.

While the AWP strategy for permitting projects is likely the most effective way to shorten and simplify the environmental permitting process, the applicant is still free to apply to each jurisdictional agency individually.

6.5 Design Steps

A **seven (7) step** approach is to be used in project planning, design, and review for all bank repair and bank stabilization projects located within the SLO Creek Watershed. Conformance with the steps listed herein is required for a project to be part of the Annual Work Plan. This detailed analysis and design approach is geared to larger project sites. Individual projects with stream stabilization needs totaling less than **15 m (50 ft)** will not normally be required to conduct the detailed geomorphic and hydraulic analysis and alternatives investigations. All proposed projects with bank stabilization needs greater than **15 m**, and requiring a grading or building permit for work along a streambank will be required to meet the submittal requirements of this section. Information on specific recommended vegetative, biotechnical, and integrated bank stabilization techniques are presented in the next section, along with example schematic drawings.

A team of professionals retained by the property owner, typically including a civil engineer, a hydrologist, a geomorphologist and/or geotechnical engineer, and a landscape architect or revegetation specialist, should develop a detailed bank stabilization project design. Consultation with a fisheries biologist or aquatic biologist is also recommended for most sites. The project design team will need to conduct a detailed and site-specific study to adapt the design schematics outlined in this section to specific site conditions.

In some cases a Conceptual Design has already been recommended in **Section 5.0** of the ***SLO Creek Waterway Management Plan***, ***Volume I*** for bank erosion sites identified in the creek inventory. For those locations, and where the project applicant agrees with the Conceptual Design, the Design Process can be simplified. However, for most sites, the design team should still complete a geomorphic and hydraulic assessment, identify potential impacts and mitigations, confirm the appropriateness of the conceptual design recommendation, and adapt the schematic design to actual site conditions and site dimensions.

6.5.1 Overview of Design Steps

Step 1 Site evaluation and Analysis

Problem Identification
Geomorphic investigation
Hydraulic analysis
Biological studies
Geotechnical investigation (where needed)
Scaled site maps

Step 2 Develop and Screen Alternatives

Define Goals and Objectives
Develop and Screen Alternatives, or confirm Waterway Management Plan design
Evaluate Alternatives
Select Preferred Alternative

Step 3 Develop Concept Plan

Refine Conceptual Bank Stabilization Plan contained in Section 5.4 of Waterway Management Plan, <u>or</u> submit new Concept Plan and Design Report

Step 4 Project Approval and Permitting:

Determine if project can be submitted as part of City or County Annual Work Plan, (AWP) associated with the Stream Management and Maintenance Program -Individual Permit; if not initiate permitting with the following:

Corps of Engineers Sect. 404 Permit
Regional Board Water Quality Certification
Fish & Game Stream Bed Alteration agreement
Review for compliance with City/County Policies and Requirements
CEQA review and compliance
Local Grading/Building Permits

Step 5 Construction Drawings

Submit Construction Drawings for Plan Check review; revise as necessary

Step 6 Construction Inspection & Monitoring

Inspection by project engineer and City or County Building/Public Works Inspector

Step 7 Post Construction Maintenance and Monitoring

Monitor project for erodibility/stability maintenance needs and conformance with mitigation requirements.

Biological inspection/monitoring for permit conditions and mitigation requirements.

6.5.2 Detailed Design Procedures

Step 1 - Site Evaluation and Analysis

- **Problem Identification**

A bank repair project design must address the fundamental and underlying problems responsible for the failure, or the project will be prone to failure at some time in the future. This includes identification of both the probable cause of failure and the mode of failure. Stabilization designs that are imposed as a solution on a site without this understanding could transfer the problem to the other side of the channel, shift it upstream or downstream, or result in failure and/or costly on-going maintenance. In addition, designs that impinge into the channel can cause local backwater flooding effects. These consequences should be anticipated and evaluated prior to project design, and the design modified to reflect these circumstances, and is a reference for geomorphic analysis: http://www.fhwa.dot.gov/bridge/hydpub.htm

Typically, causative factors are grouped according to whether they are from: (1) regional hydraulic forces such as high shear stresses and altered runoff patterns, and consequent channel incision; (2) local hydraulic forces such as from a fallen tree trunk diverting flow against the bank, or other problems from sediment or debris accumulation; or (3) geotechnical instabilities such as soft or weak bank soils, and/or prolonged channel bank saturation. Most often several causes and modes of failure act together at a site, so that it may not always possible to determine a single causative factor. The Federal Highway Administration Hydraulic Engineering Circular (HEC) 20 lists some common kinds of failure and is referenced for geomorphic analysis at *http://www.fhwa.dot.gov/bridge/hydpub.htm.*

A geomorphic and hydraulic analysis of the proposed bank repair and bank stabilization site, for existing conditions and proposed design alternatives, must be completed for all projects greater than ***15 meters (50 feet)*** in creek length. Most of the information necessary to complete this analysis (for the main stem of SLO Creek and its major tributaries) is contained in the resource inventory (**Appendix A**) to the SLO Creek Waterway Management Plan. The intent here is that the project designer be required to consult the information, update it and supplement it as required, and actually use the geomorphic and hydraulic information in the design analysis.

- **Geomorphic Analysis:**

The goal of a fluvial geomorphic evaluation completed as part of a bank repair project is to identify current and historic causes of instability and to understand their short and long-term effects. The geomorphic analysis should look at three features of a stream:

- Changes and instabilities in channel planform, or the shape of the channel, particularly lateral erosion and migration of channel bends over time;
- Channel bedform or bed features, such as occurrence of rock outcrops, head cuts, and sediment bars, their stability over time, and migration down stream, and;
- Channel profile or channel bed slope, indicating anomalies, knick points, and historic creek bed incision or sedimentation.

The geomorphic analysis should be completed both upstream and downstream of the project site to put the project in proper perspective and gain the necessary understanding of the fluvial system. The analysis should typically extend a minimum of 150 meters (500 feet) upstream and downstream of the project site.

The cause, extent, and severity of the problem must be determined- is the failure due to:

- Toe scour and removal of toe support;
- Channel incision creating bank slopes too high for the bank materials to support from changed watershed hydrology;
- Loss of protective vegetation and high stream velocities;
- Channel migration at bends;
- Unstable soil and geologic conditions, such as slump or earthflows; or
- Local flow deflection caused by downed trees, channel constrictions, or other flow obstructions.

The Federal Highway Administration Hydraulic Engineer Circular 20 - HEC 20 provides nomenclature that can be utilized in classifying and determining failure types.

The analysis should include developing information on channel planform stability using:

- Sequence of historic aerial photography and maps
- Longitudinal profile of the thalweg to identify steep gradients and other anomalies
- Mapping of bank and bed conditions

- Identification of substrate, pebble counts, and rock masses.

If older long profiles and cross sections are available, then a comparison can reveal information about the stability of the channel bottom, whether the bed is eroding or accreting sediment. Characterization of such geomorphic features as channel width, depth, and hydraulic radius and a classification scheme such as the Rosgen Stream Classification should also be submitted (Rosgen, D., 1996).

- **Hydraulic Analysis**

Hydraulic analysis consists of two steps:

1. Design hydraulics to develop design criteria such as ordinary high water and flood water surface elevations, stream velocities and shear forces; and

2. Hydraulic impact assessment to insure that the proposed project will not cause local flooding, or cross-bank or downstream erosion problems, for instance, by increasing downstream velocity. ***Section 4.1*** provides guidance in completing hydrologic and hydraulic analysis of project sites.

Depth of placement of the structure must also take into account anticipated long-term channel incision, or appropriate bed control structures must be included in the design. Quantitative estimates of channel erosion or deposition rates can be obtained from the time sequence comparison of surveyed cross sections, from maps and aerial photographs, historical records, or observations at bridge piers, walls, and other historic structures in the stream bed.

- **Hydraulic Modeling Requirements**

A hydraulic model will be required for all projects impacting more that 15 m (50 ft.) of channel length and for all projects located within the boundaries of the Zone 9 HEC-RAS hydraulic model of SLO, Stenner, Brizziolari, Acacia, Orcutt, and East Fork San Luis Obispo creeks. The proposed model is to develop design shear stress levels along the eroding bank and to show that the project will have no adverse impacts to nearby water surface elevations.

The SLO/Zone 9 HEC-RAS hydraulic model is an acceptable tool to use for analysis. However, since the model was constructed using widely spaced cross-sections (every 50-150 meters), it may be advisable to survey in some new cross-sections (on the 1988 vertical datum) and add these to the channel model to create a more localized and accurate model of the project site. Cross-section spacings of 15 meters are recommended for design hydraulic analysis. Alternatively, a new model could be developed at the site. A factor of safety, in addition to the bend correction factor should be added to the computed shear force and be sufficiently large to account for any local flow concentrations that might occur within the project reach. A typical range is 1.4 to 2.0, with the lower safety factor used where no habitable structures need to be protected, and the higher factor used for residential or commercial buildings.

Shear Stress-Based Stream Bank Stability Analysis Theory

Several simple desktop calculation methods and simple to use models exist for quantitatively analyzing the erosive potential of flow and the erosion resistance of bank materials. The most commonly used methods for analyzing erosive potential involve computations of flow velocity (permissive velocity) and/or boundary shear stress (permissive shear). This Design Manual uses boundary shear stress as the primary design criterion for biotechnical and other bank stabilization projects. One of the reasons is that shear stress is a direct measure of the forces experienced by a bank during erosive events, while velocities alone do not directly cause erosion. Secondly, it is easier to account for spatial variation in shear stresses vertically along a streambanks than it is to describe a similar variation in velocity. Finally, calculating shear stress is relatively straightforward.

The average amount of boundary shear stress that occurs on any given cross section can be calculated using relatively simple mathematics, a few physical principals, and some simplifying assumptions. A qualitative description is presented below:

Take a slice of water flowing down a typical stream. Assume it is neither accelerating nor decelerating, so that the only force acting on the slice of water is that of gravity. Gravity always acts in the downward direction, but the gravity vector can be broken up into a section perpendicular to the streambed and a portion parallel to the streambed. The perpendicular part is the pressure felt by the bed of the stream and is not of primary importance as far as erosion is concerned. The parallel part is the tractive or shearing stress on the bed of the stream that tends to entrain particles and can be thought of as the erosive force of the flow. The relationship is described in ***Equation 6-1***.

The gravity force, and correspondingly the shear and normal forces on the bed, increase proportionately with the weight of water, which is itself proportional to the depth of flow. The size of the shear force in relationship to the normal force increases with channel slope. With a few more assumptions, it becomes apparent that the average shear stress throughout a stream channel is proportional to the hydraulic radius (flow cross-sectional area divided by wetted perimeter) of the channel in a similar way to how the shear force in the slice is proportional to depth.

To correct for the natural variation in shear stress within a channel, several simple empirical relationships and a factor of safety should be used. The value to start with is not the cross section average shear stress (because the shear on the bed is in reality somewhat higher) but the "maximum average" shear stress felt in the deepest part of the channel (***Equation 6-2***). Then, an adjustment factor is applied to the base shear stress to account for increases caused by bends in the stream *(U.S. Dept. of Transportation, HEC-20, 1988*). Once a maximum channel shear stress is computed for the deepest part of the channel (for design purposes, the base of the bank), compute the reduction that should occur as one moves up the banks. This is a simple linear relationship, based on ***Equation 6-2***, with the peak shear stress being located at the bed and zero shear at the water surface.

Equation 6-1 $\tau_{ave}=\gamma RS$

where:

τ_{ave} = Cross-section average shear stress
γ = Specific weight of water
R = Hydraulic radius (cross-sectional area/wetted perimeter)
S = Water surface slope

Equation 6-2 $\tau_{toe} = \gamma DS$

where:

τ_{toe} = Shear stress at bank toe
D = Depth of flow
γ = Specific weight of water
S = Water surface slope

If the bank erosion problem occurs near a channel bend, a bend adjustment factor should be used for correcting shear stresses along the bend's outer bank. FHWA-HEC-15 provides guidance in bend sheer correction. The corrected bank toe shear stress, multiplied by an appropriate factor of safety, can then be used to compute a vertical shear stress distribution on the bank. The factor of safety should be sufficiently large to account for any local flow concentrations that might occur within the project reach.

Where there are significant natural or structural encroachments or constrictions, which may cause backwater effects, complete stepwise backwater calculations.

Use of Shear Stress Data

The hydraulic model results for velocities and shear forces should be compared with the shear strength and shear resistance values in ***Table 6-1*** as a guide to selection of appropriate channel protection material. A biodegradable erosion control blanket or other temporary measures need to be employed to provide bank protection before the 3-4 year grow-in period of protection is achieved.

Table 6-1
Shear Stress Tolerance of Bank Slope Protection

Treatment Approach	***Directly After Installation***		***After 3 to 4 Growing Seasons***	
	(N/m^2)	***(lb/ft2)***	***(N/m2)***	***(lb/ft2)***
Turf/Grass	10	0.2	100	2.1
Reed Plantings	5	0.1	30	0.6
Reed Rolls, biologs	30	0.6	60	1.3
Live fascine	60	1.3	80	1.7
Willow brush layer	20	0.4	140	2.9
Willow mat	50	1.0	300	6.3
Hard wood plantings	20	0.4	120	2.5
Branch packing, brush mattress	100	2.1	300	6.3
Small rock revetment with live stakes	200	4.2	300	6.3
Boulder sized rip-rap, unplanted	-	-	250	5.2
Concrete wall, cement blocks	-	-	600	12.5
Gabion structures, planted	400	8.4	500	10.4

Source: Modified from *Schiechtl and Stern, 1994*

Re-run the model after coding in the proposed channel protection alternatives, including any new cross-section that indicates encroachment into the channel, or for bank protection materials and plantings that changes the Mannings "n" value. The 25- year discharge as contained in the Waterway Management Plan - Hydrology/Hydraulics report (**Appendix C**) or the bank full discharge, should be used for the design of bank erosion protection for projects where no structure is at risk, with the 50-year flow used where a structure is directly threatened. However, the design flow rate for the channel as contained in **Section 5.2** should be used to ensure that the project does not increase floodwater surface elevations.

Summarize the results in a table showing both existing conditions and proposed design conditions for water surface elevations, velocities, and average shear force at the project, and upstream and downstream 100 meters.

Once design shear stresses have been determined, the next step is to start evaluating biotechnical stabilization techniques for applicability. Typical values of allowable shear stress for a number of biotechnical stabilization techniques have been published. Typically biotechnical projects can be effectively used along streams where shear forces are in the range of 100 to 300 N/M^2 (2 to 6 lb/ft^2). Some of these values have been determined in individual experiments, while others were developed by product manufacturers. Care should be taken to ensure that the duration of erosive flows at the project site are not likely to be longer than was used for testing a particular biotechnical stabilization technique.

Another point to consider is the variation in allowable shear that occurs as a planted biotechnical project matures. It is sometimes difficult to achieve the desirable value based solely on vegetation, so a combination of erosion control fabric and vegetation is typically required.

Depth of Scour

Another important design variable is depth of scour. The estimated scour depth is used to identify the depth to which bank toe protection must be placed to be stable at a particular discharge. Field indications of scour depth at nearby channel locations should be the primary source of estimated scour depth information. However, several formulas originally developed to predict scour around bridge abutments can be used if the proposed project will encroach on the channel.

Depth of scour around embankments can be determined using the Lui formula:

$$\underline{D}s = c\ (a/D_o)^{0.40}\ \times\ (F_o)^{0.33}$$

Where :
D_s= depth of scour below mean bed elevation (ft.)
a = embankment encroachment into channel, normal to wall or bank (ft.)/Do
D_o = mean depth of flow upstream of embankment(ft.)
F_o = Froude No. of approaching flow (V_o= gD_o) ^{½}

For higher values of a/D_o, use the Colorado State University formula:

$$\frac{D_s}{D_o} = 4\ (F_o)^{0.33}$$

- **Geotechnical Analysis:**

In addition to a geomorphic and hydraulic evaluation, a geotechnical review should be completed by a California Registered Geologist, Engineering Geologist or Geotechnical Engineer whenever deep-seated or mass failure is suspect at a site, for proposed vertical retaining structures, or where slopes steeper than 2.5H:1V are proposed. The City/County may require such an investigation, based on their review of the site and surrounding area. The geotechnical analysis requirement should include mapping surficial features and failure areas, and a program of drilling and laboratory testing to determine index soil properties and soil shear strengths necessary for geotechnical analysis and design. The drilling and laboratory analysis program may be necessary to describe foundation bearing conditions and drainage requirements, especially where retaining walls and crib walls are under consideration. Use of a slope stability model such as Slope-W is an efficient way to determine geotechnical stability for banks over 3.5 meters (12 feet) high. Soil shear strength and engineering index properties, weak soil conditions and potential failure surfaces should be identified and described in a Geotechnical Report, or as a geotechnical section of a overall bank stabilization Conceptual Design Report.

- **Biological Analysis:**

An assessment of existing biological conditions and potential project impacts on riparian habitat, fisheries, and water quality and aquatic species should be completed prior to preparing a conceptual design so that impacts are minimized. Special attention should be paid to characterizing the occurrence of shaded pools and overhanging banks, and the presence of woody debris in the vicinity of the project site. Some of the stream biology information is available in the creek inventories that were completed as part of the studies for the Waterway Management Plan. Depending on the creek reach, a protocol search for endangered species may also be required, and appropriate mitigations developed.

A Biological Assessment should be prepared that identifies and maps jurisdictional wetlands, endangered species, aquatic habitat and fisheries protection needs. For small projects this can be included as a section of the Conceptual Design Report. The Assessment should also include recommendations for aquatic habitat enhancement, for instance by recommending the location and placement of such in-stream structures as root-wads or channel boulders to create stable pool features. The California Salmonid Stream Habitat Restoration Manual (Flossi, 1998) should be referred to for design considerations for these in-stream structures. The project biologist can also help to determine plant suitability based on local microclimates and soil conditions for riparian habitat mitigation and biotechnical planting selection and specification (see ***Section 11.0***).

- **Construction Factors**

The design team should also identify site and channel access and work conditions, restricted seasons, mobilization and materials storage areas and needs, and the need for and allowable methods of flow diversion and dewatering. Do not leave these factors up to the construction contractor, but include construction details, limits of work, diversion methods, access and mobilization sites, etc. in the Conceptual Design Report and detail them in the project Plans and Specifications.

Step 2 - Develop and Screen Alternatives

- **Define Project Goals and Objectives**

It is important to define the Goals and Objectives early on in the bank repair planning process as a tool to be used in formulating and screening alternatives. In particular Goals and Objectives for Habitat Protection, Restoration, and Enhancement need to be determined as part of possible project mitigation requirements. In general use of a vegetative or biotechnical approach should be given highest consideration as this approach will result in most impacts to wetlands being mitigated on site through inclusion of aquatic and habitat elements in the project design. The design should also consider including additional adjacent area, such as top of bank planting, or upstream/downstream aquatic habitat enhancement through installation of channel boulders and root wads.

Most projects should be multi-objective with property protection, bank protection, habitat enhancement, and water quality protection foremost. Common Goals and Objectives include:

- ***Affordability*** - what is the most cost effective solution, and what are the costs relative to other alternatives and benefits?

- ***Acceptability*** - what is acceptable to the property owner, environmental interest groups, neighbors, and local government in terms of biological and water quality impacts, loss of property, appearance, and access and recreation issues.

- ***Permitting*** **-** the plans should be consistent with City and County policy and regulations and should not conflict with state and federal regulations governing activities in navigable waters, wetlands, floodplains, endangered species habitat and riparian corridors.

- ***Sustainability*** - the project should provide the risk and hazard reduction targeted for the design flow and shear forces at the site in terms of durability and maintenance needs.

Generally a review and evaluation of design alternatives is required by most permitting agencies to insure the least environmentally damaging, technically and economically feasible alternative is selected. ***Table 6-2*** summarizes the screening criteria to be used for the various channel bank stabilization alternatives. This table, when completed and submitted by the project applicant, is intended to provide a ready reference and support to the recommendations made for the various kinds of bank stabilization structures considered. The most environmentally sensitive and practical solution should be chosen as the preferred stabilization plan.

Alternatives should be developed and evaluated with the following questions in mind:

The No Action Alternative
If no action is taken can the fluvial system heal itself at this location in a reasonable amount of time without causing or contributing to other problems? Is there room for the channel to meander with appropriate setbacks?

The Minimum Interference Alternative
If a minimum amount of work is done to "clean and dress" the problem, will the fluvial system heal itself at this location in a reasonable amount of time without causing or contributing to other problems?

Flexible Boundary Alternative
Can biotechnical stabilization measures secure this bank? Is there sufficient capacity to convey the design flow with an increase in vegetative roughness? Is there right-of-way flexibility to accommodate natural geomorphic processes? Is restoration of this reach valuable as mitigation for another problem area?

Rigid Boundary Alternative
Is some form of hard bank protection required due to hydraulic constraints, public safety concerns, or to protect from the loss of private or public property, and can the consequences of this approach be kept on-site? Can some vegetation be accommodated with the hard structures?

Integrated Solution Alternative
How high up the bank is a rigid structure required? How far laterally? Can a combination of approaches, such as a hard toe and soft vegetated top work? Can the project transition to stable areas using a soft approach?

Short-term vs. Long-term Alternative
Is this a reach that could be better served by inclusion in future, larger scale projects? Is the risk imminent; are there interim solutions that long-term projects can build upon?

- **Alternatives Screening and Project Evaluation**

Most channel modifications to a creek system can have consequences upstream and down stream from the project area. These consequences should be anticipated and evaluated prior to construction. Impingement into the stream by hard structures can cause a local backwater effect, raising water surface elevations and/or causing sediment accumulation. Channel constrictions from bank repair projects can also accelerate flow immediately downstream, causing scour and increasing bank erosion risk. Hard structures can force and deflect flow against the opposite bank. The hydraulic model constructed to define existing conditions should also be used to evaluate the consequences of alternative channel modifications. Unfortunately, standard one-dimensional hydraulic models cannot determine the consequences of possible flow deflection; this evaluation must be left to the judgment and experience of the project team.

In addition to hydrologic evaluation, geotechnical review and an assessment of potential impacts on riparian habitat, fisheries, and water quality and aquatic species should be completed as a prelude to Conceptual Design so that impacts are minimized.

To be considered potentially acceptable and worthy of further consideration, the potential bank stabilization approach must successfully meet the following criteria:

- ***Environmental***. The least environmentally damaging alternative consistent with subsequent criteria (cost and durability) should be selected. There should be no net loss of aquatic, wetlands, or riparian habitat from the project design.

- ***Cost***. The design must be cost effective, and have a favorable benefit-cost ratio. The benefits (property protection) must exceed project costs. The incremental environmental benefits from a "softer" approach should not be greatly overshadowed by increased costs.

- ***Durability***. The project must be long lasting, with a design life of at least 25 years. The project should be designed to handle at least the 25-year flood velocities where structures are not at risk, and increasing to at least the 50-year flood where valuable structures are potentially at risk. Comparison of calculated toe shear stress and the shear strength of the stabilization approach is a good test of durability.

- ***Maintenance***. Maintenance costs should be low. Typically annual maintenance costs should be less than 1/20th of the cost of the structure.

- ***Flow Deflection***. Generally, the project should not deflect flows downstream against unprotected banks.

- ***Channel Conveyance Effects***. The design should not create an increased water surface elevation (through channel constriction) of more than 0.1 meter, as estimated by HEC-RAS or HEC-2 analysis for the 100-year flood event.

Table 6-2

Bank Stabilization Alternatives Screening Analysis

Project Alternative	Environmental	Cost	Durability	Maintenance	Flow Deflection	Conveyance	Comment
No Project							Does not meet project goals, riparian vegetation endangered some sites
Rigid, Inflexible Hard Structures (retaining walls)							Best use extreme velocities, geotechnical problems, high value property
Flexible Hard Structures (gabions, rip-rap)							Can withstand wide range of velocities and shear forces, but generally allows less vegetation than flexible liners or integrated
Flexible (soft) Approaches, including (Vegetative & Biotechnical)							Uses limited to velocities less the 1.5 mps
Integrated Approaches (Crib walls, planted rip rap, geogrids							Depending on toe protection, uses limited to velocities less than 2.5-3 mps

List the alternatives considered in a column along the left side of a table similar to **6-2**.
Fill in the chart using the following symbols for each alternative reviewed:
+ Substantially meets criteria
0 Neutral,
- Does not effectively meet criteria, may require mitigation

Step 3 - Develop Concept Plan and Design Report

After developing and screening project alternatives and selection of the preferred alternative, a Concept Plan and Design Report should be prepared and submitted to the City or County for preliminary review. This process can be condensed for those projects where a preferred Concept Bank Stabilization Plan has been identified in the Waterway Management Plan (see Section 5.4, Bank Stabilization Program of the Waterway Plan), and where the project applicant agrees to the concept outlined in the Waterway Management Plan. The objective of this step is to provide a preliminary review and confirmation of the design concept before time and effort is spent in preparing detailed construction drawings, and in permitting and project approval.

For project locations where no recommended design was included in the Waterway Management Plan, or where the applicant wishes to submit a revised concept, then a design report Concept Plan will be required. The preferred plan alternative as selected in step 2 should be refined and developed into the Concept Plan that will be the basis for subsequent environmental and permit review. The Concept Plan should portray graphically (through sketches, and plan, profile, and cross-section drawings) the approach to bank stabilization that deals with all of the design factors and constraints. The Concept Plan is best considered to be a tool for conveying ideas and information to the plan and permit reviewers, and provides the basis to guide the subsequent development of the more detailed Construction Drawings. Planning level cost estimates developed for the alternatives analyses should be refined at this stage for public projects.

The Concept Plan Design Report should be submitted to the appropriate City and County Departments for review and approval along with any permit application paperwork. The applicant should also notify the City or County if the Concept Plan is to be included in the Annual Work Plan (AWP). The Concept Plan should include a discussion of the site constraints, information on the geomorphic, hydraulic, and biological investigations including and recommendations, the geotechnical report, (if required), the alternatives evaluated, and the rationale for selection of the preferred alternative. This will be especially important if a purely structural approach is proposed.

Step 4 - Local, State and Federal agency permitting and project approval

The City of SLO and Zone 9 have applied for a long-term Individual Permit from state and federal agencies, that once approved, will allow for most routine stream maintenance activities, including construction of bank repair and bank stabilization projects. The proposed permit conditions submitted by the City and Zone 9 will stipulate that vegetative and biotechnical approaches to bank repair will be the preferred approach, and that structural bank stabilization will be used only sparingly at highly constrained sites. Repair projects will be allowed within the same footprint of the failing structure and using the same design approach, retrofitted with native plantings where possible.

Several federal, state, and local agencies have responsibilities for the protection of wetlands and creeks in the San Luis Obispo County area. The U.S. Army Corps of Engineers (ACOE), California Department of Fish and Game (CDFG), and the Central Coast Regional Water Quality Control Board (RWQCB), all require permits and/or approvals for projects that may affect wetlands and creeks, including streambank stabilization projects. If the applicant's project is not included in an AWP by the City or County, and was not subject to any CEQA or other regulatory review as part of the review of the Waterway Management Plan, then the following agencies should be contacted to determine whether or not a project requires their approval.

U.S. Army Corps of Engineers 404 Permit - If the project proposes removal or placement of any materials in the stream area, or if the project area is a wetland, then the applicant must apply to the ACOE to determine if a Section 404 permit is necessary, pursuant to the Clean Water Act.

Department of Fish and Game Section 1601/1603 - A Streambed Alteration Agreement is necessary to perform any physical manipulation of the stream, including vegetation planting or removal, below the high water mark.

Regional Water Quality Control Board Water Quality Certification - Section 401 of the Clean Water Act requires that RWQCBs determine consistency (Water Quality certification or waiver) between proposed projects, California water quality laws, and certain sections of the Clean Water Act.

City of SLO or SLO County Grading/Building Permit - A local permit issued by the City or County is required for any excavation or fill that will encroach on or alter a natural drainage channel or water course, including adjacent floodplain areas. In addition some kinds of structural stabilization approaches, such as a live crib wall will require a building permit. The plan reviewer may request a copy of the project geotechnical report and structural calculations and analysis.

California Environmental Quality Act - Any time permits are required to be issued by the City, County, the Department of Fish and Game, or the Regional Board and the Army Corps of Engineers, an environmental review is necessary. Depending on the specific project parameters, a Negative Declaration, a Focused Expanded Initial Study/ Mitigated Negative Declaration or focused Environmental Impact Report may be required. Certain small repair and replacement projects may be "Exempt" from environmental review.

Endangered Species Act- The U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS)) enforces the federal Endangered Species Act (ESA) rules that prohibit the "taking" of listed species through human activities. The National Marine Fisheries Service enforces the ESA for marine fishes, which in SLO County is mainly steelhead trout. The principal species of concern of the USFWS along stream corridors is the red-legged frog, but there are other species of concern that also must be considered. In its permit processing, the Corps of Engineers will contact USFWS and/or NMFS to determine whether a proposed activity may impact a listed species.

Legally it is up to the applicant to show that species are not impacted, and if the Corps is not involved in the permit processing under a Nationwide Permit, or a Regional Programmatic permit, then the landowner must contact the USFWS or NMFS directly. “Taking” means destroying a species ability to breed, feed, or find shelter, and includes taking as result of a erosion/siltation, landslide, mudflow, or bank failure from a poorly designed and executed management action or construction project.

The City and County environmental review officer will assist the applicant in determining which permits are necessary from which agencies, and how the project can be dealt with in an efficient and expedited fashion if it is consistent with this design handbook and the Stream Management and Maintenance Program manual.

Step 5 - Preparation and Submittal of Construction Plans and Specifications

Both the City of San Luis Obispo and SLO County have adopted the latest version of the California Department of Transportation (Caltrans) Standard Plans and Standard Specifications as their basic design manuals. These contain very exacting standards and the same level of detail will generally be necessary for Construction Drawings for private construction projects along creeks. The final approved Concept Plan and Design Report as modified during the permit review and approval process will form the basis for preparation of the Construction Plans and Specifications.

Preparing formal Plans and Specifications, including the Engineer’s Estimate of Probable Costs will help ensure that the constructed project meets all of the project Goals and Objectives and considers all of the regulatory requirements and design constraints. For Public Works projects the Plans and Specifications should include the following:

- Contractual language including method of measuring work for payment, and applicable unit and lump sum costs, bonds and retentions;
- Method for change orders and payment provisions for unforeseen circumstances;
- Construction schedule and any penalties for delayed work;
- Detailed description of the Scope of Work;
- Materials specifications and suppliers list;
- Construction methods, tolerances and work requirements;
- Access, right-of-way, utilities, limits of work, mobilization and staging areas;
- Plan sheets, details, and typical cross sections; (following City/County Engineering Standards)
- Notifications, submittals, and construction inspection;
- Regulatory requirements, permit conditions, and work restrictions;
- Plan for water diversion and de-watering, and construction erosion control (SWPPP)
- Plan for protection or relocation of sensitive aquatic vertebrate species and fish
- Post- construction maintenance and monitoring requirements.

Step 6 - Construction Observation, Inspection and Monitoring

For large streambank repair and stabilization, and revegetation projects on-site construction inspection will be performed by City/County staff or contract inspectors. This will include both public projects and privately constructed projects. The purpose will be to interpret plans (for public works projects), to insure that the project plans and specifications are followed, and that sensitive areas, including any sensitive species, fisheries and water quality protection measures are correctly implemented according to the conditions of the permit and approved project plans.

The City/County inspectors will insure that appropriate construction quality control procedures are followed and documented for the record. This is especially important for construction contractors not familiar with biotechnical bank stabilization methods, which often cannot be specified to the same level of detail as more traditional bank stabilization projects, and may require more field adjustments and field decisions. Proper location, handling and installation of structures and plant materials are critically important, and the project designer may need to provide on-site direction, as they are most familiar with the construction design intent. The construction inspector will also need to resolve problems with specifications and materials, approve changes, and deal with unforeseen problems and difficulties, particularly any geotechnical and drainage problems uncovered during soil excavation and foundation preparation. Any field changes will be documented in a project As-Built Plan.

Construction site erosion control, stream diversion and water handling methods will be a main focus of the review and construction inspection. For public projects, the City or County will normally have a project biologist/monitor that will assist in construction observation and to insure that appropriate water quality, wetlands, and sensitive species protection protocols are being followed. The City, County, or other regulatory agencies may also require a biologist/monitor be on site for private construction projects. The City/County inspector, and project biologist/monitor will be given the authority to shut down or suspend work at a project site as appropriate if the terms of the construction plans and permit conditions are not being followed. If historically or archaeologically significant objects are uncovered, the City and County will also normally shut down a project until an expert review by a qualified archeologist is completed and appropriate recommendations and mitigations are developed.

It is emphasized here that the construction contractor is responsible for complying with all permit conditions relating to erosion and sediment control, traffic and job site safety, and compliance with regulatory permit conditions, especially those relating to the Endangered Species Act.

Step 7 - Post-Construction Maintenance and Monitoring

A program of observation, monitoring, maintenance and management is very important to insure project success for vegetative and biotechnical designs which depend on successful plant establishment for erosion protection and bank stabilization. Most repair project sites should be visited, inspected for damage and planting success, and photographed following all major storm flows, and at least monthly during the first growing season. Replanting, maintenance of the irrigation system, weeding and pest control, and re-securing erosion blankets and fiber rolls may be necessary, as well as other work such as additional rock placement, filling any voids with smaller rock and soil, and joint planting additional willows and other woody species.

A minimum three-year maintenance contract should be included in the construction contract for large bank stabilization management public projects, particularly those that utilize vegetative and biotechnical approaches. The City/County may also require private parties to contract with a biologist or landscape contractor to monitor and maintain the restoration and stabilization site's irrigation and landscaping/ native plantings.

Often the permit conditions issued by the regulatory agencies will require submittal of a Habitat Mitigation and Monitoring Plan, which will outline maintenance and monitoring protocols, times, and methods, and provide specific success criteria against which the monitoring results are to be judged.

6.6 Acceptable Bank Stabilization Structures

This section describes a number of traditional and alternative approaches to bank stabilization. Diagrammatic sketches of alternative bank stabilization structures as abstracted mainly from USDA NRCS Engineering Field Handbook, Chapter 16, "Streambanks and Shoreline Protection" are presented in ***Figures 6-1*** *through* ***6-17*** (*USDA NRCS, 1998*). Other sources of information included, Flosi, et al. (1998), U.S. Army Corps of Engineers (1997), Schiechtl and Stern (1996), Gray and Leisure (1992), and Reiley (1998). These sketches are intended to show the general approach to the design, and in many cases will need to be substantially modified to meet site conditions.

This information is intended to replace City of San Luis Obispo Section B-1, ***Standards for Improvement of Waterways of the 1983 Flood Management Policy.***

6.6.1 Vegetative and Biotechnical Approaches

In selecting an approach using biotechnical methods, the following should be considered:

1. Vegetative and biotechnical methods require a "grow-in" period and may require temporary erosion control blankets

2. These methods typically are not strong enough to provide toe protection, particularly at channel bends, where shear forces are highest and where most of the initial failure occurs.

3. These methods typically can provide stability into the bank only 1 to 1.5 meters (3 to 5 feet) deep and cannot address deeper-seated failure zones.

- **Live Staking and Willow Wattling**. These techniques utilize live cuttings or slips of sprouting and fast growing riparian plants to stabilize bank slopes by buffering flow with above ground foliage, while providing soil stabilization with root growth. Willow wattles (also called live fascines) are long bundles of branch cuttings bound together in cylindrical structures (***Figure 6-1***). They are placed in shallow trenches on contour. They are principally used to prevent slope erosion and very shallow slumping and rilling**.** Since these techniques rely on rapid plant growth for stabilization, they are best used on sunny sites, or in combination with erosion control blankets at most bank repair sites.

- **Erosion Control Fabric Planted w. Rooted Trees/Shrubs**. This technique involves preparing a smooth surface along the upper bank, seeding with grass and appropriate fertilizer, and covering this surface with an appropriate biodegradable erosion control fabric (***Figure 6-2***). The erosion control fabric provides temporary protection against surface rilling and gullying while the grass becomes established and, when properly installed and stapled to the ground, can provide protection against scour from high stream flow. Rooted native trees and shrubs selected based on the sun and water availability on the bank are planted through the erosion control fabric at relatively close spacings. These plantings are then irrigated periodically for several years until they become permanently established and can be counted on for permanent scour protection for the upper bank. *This is one of the most labor-intensive upper bank protection techniques and is the preferred alternative for projects where toe erosion or stream velocities are not high or where equipment access is poor. At some locations use of rock toe protection is needed with this technique.*

- **Brush Layering**. This technique is also called branch packing. It consists of constructing a slope fill section by alternating layers of live sprouting branches and compacted earth backfill (***Figure 6-3***). The front of the live branches should protrude slightly into the channel, while it is important that the butt ends contact native bank soils at the rear of the fill. Brush layering can be used to repair small, localized slumps and holes in streambanks. The upper limit of the fill section should be less than 2.7 to 3 meters (9 or 10 feet) in thickness, while depth can extend back 2.4 to 3 meters (8 to 10 feet). Fill sections are designed in consideration of soil conditions, slope, and water velocities. Typical vertical section spacing ranges from .9 to 1.5 meters (3 to5 feet), and slopes as steep as 1.5H: 1V can be constructed. *This technique has limitations on dry or shady sites.*

- **Brush Mattress**. A brush mattress is a combination of live stakes (usually willow), live fascines or willow wattles, and branch cuttings installed to cover and stabilize eroding streambanks (***Figure 6-4***). Usually twine or wire constructed and held in place using stout stakes as a sort of cross-laced grid system is used to hold the brush down until some of it begins to sprout. This method can be used to form a live armor against fast flowing water with abrasive power, but is less effective combating toe scour or slumping. The brush layer is usually cross-tied to the slope using stakes and rope or wire. Adequate channel flow capacity must also exist. *This technique is best used in rural areas where there is a supply of brush near the job site, where inexpensive labor is available, and where banks are not particularly steep or high.*

- **Fiber rolls/ fiber rock rolls/ coir erosion blankets.** Fiber rolls are cylindrical structures filled with coconut husk fibers bound together with twine woven from coconut (***Figure 6-5***) Typically they are available in 304 mm to 457 mm (12 or 18 inches) diameter sizes and 6- meters (20-foot) lengths. Fiber rock rolls are similar but the twisted twine encasement is constructed of long lasting synthetic rope and the structure is filled with rounded stream cobbles, sometimes available on site. Often several rolls are stacked atop each other with the lowest structures composed of rock rolls buried in a trench and anchored using hooked rebar, with fiber rolls (sometimes called biologs) placed atop. These structures are very flexible and adaptable, conforming to irregularities of the bank with little need for excavation and site disturbance. The fiber rolls can also be used to transition upstream and downstream from planted rock rip-rap sites. Often they can be entirely constructed using hand labor. Live willow stakes are inserted through or between the rolls, which gradually degrade as they trap sediment. Many times a biodegradable erosion blanket and live willow staking is used on the slope above the roll stabilized toe. *This alternative should often be used as a transition between harder techniques and upstream/downstream unprotected banks*

6.6.2 Structural and Integrated Approaches

- **Vegetated geogrids** are earth-filled structures enveloped in natural or synthetic geotextile materials (***Figure 6-6***). The soil lifts are end-wrapped on the creek channel side with layers of live brush or willow cuttings placed between the lifts. Typically, the geogrids are established on a foundation of rock fill, placed on the channel bottom. Vegetated geogrids can be constructed with a slope of 0.5H:1V. *Vegetated geogrids can sometimes be an expensive alternative where reconstruction of steep slopes is not required. However, they can be incorporated for several feet above rock rip-rap or A-jacks toe protection.*

- **Live crib-walls** consist of a box-like interlocking arrangement of log, timber, or concrete members that are backfilled with layers of soil, and with live brush cuttings extending through openings into the channel bank and open channel (***Figure 6-7***). Properly designed, they can withstand very high channel velocities and shear forces. Since they are somewhat inflexible, a stable foundation, and protection from scour and undermining are critical. Live crib walls can be constructed nearly vertical. *This technique would be used when a vertical bank is needed. It is not applicable at many sites for cost reasons*

- **Planted rock rip-rap** consists of a specially constructed rock rip-rap structure that has soil and live stakes (usually willows, sometimes cottonwoods) inserted into the open voids or joints between the rock (***Figure 6-8***). Design issues include selection of rock size and gradation, depth of toe placement, and height on the embankment in consideration of flow velocities, flow depth, and scour depth. The objective is to limit the height of the structure while also limiting encroachment into the channel or top of bank zone necessitated when laying the slope back. The rock structure is best constructed in stages or lifts working up-slope to allow insertion of soil and live willow stakes. Planted rock rip-rap has been constructed on slopes as steep as 1.25H:1V, but 2H:1V or 2.5H:1V slopes are more common. ***Section 6.6*** provides the recommended method for sizing rock. *Because of its relatively low cost and proven track record, this is often the preferred toe protection alternative.*

- **A-Jacks** are a potentially cost-effective alternative to rock rip-rap or other hard toe protection techniques. They consist of a three dimensional star shaped structure (similar in shape to children's jacks) constructed from concrete (***Figure 6-9***). Rows of A-Jacks are assembled to interlock in horizontal and vertical directions. Typically they have a pyramidal structure, with a base of three to four, or more units, decreasing in number with height. The voids in the matrix are back filled with soil and planted to native riparian trees and shrubs. Commonly 609-mm (24-inches) A-Jacks are used in moderately sized streams, are toed in 0.3 to 6 meters (1 to 2 ft.), and rise in height from 1.2 to 2 meters (4 to 7 feet). The 609- mm (24-inches) A-Jacks weigh 35 kilograms (78 pounds) and can be constructed using hand labor or light equipment. Willow staking, willow wattling, erosion blankets, or other upper slope biotechnical approaches are well suited for use with A-Jacks. *A-jacks do have aesthetic limitations that need to be taken into consideration for use at some highly visible sites.*

- **Traditional placed rock rip-rap** consists simply of placement of rock on existing slopes. Often, this technique has been employed with little or no slope preparation, but generally a toe trench is constructed and key-ways are excavated into the bank at either end of the revetment. When carefully constructed, rocks can be placed around obstacles such as trees. This technique requires careful selection and placement of rock material. *This technique is not recommended for widespread usage in the SLO creek watershed because of concern over biological and geomorphic impacts.*

- **Loose rock rip-rap** consists simply of placement of rock on existing slopes grades with little or no slope preparation. Generally a toe structure is not constructed. The advantage of this method is that rocks can be placed around obstacles such as trees. The disadvantage is that the finished embankment is not as stable as a properly engineered and constructed slope, because of the possible lack of toe support and the fact that frequently the slopes are steep, to 1H:1V. Sometimes pipes are driven into the toe of the channel to provide support for the loser rack. This technique requires careful selection and placement of rock material. As with planted rock rip-rap, live willow stakes can be inserted in voids between rocks. *Loose rock can often be used as a transition structure upstream and downstream from the main bank protection element.*

- **Concrete block walls** can be constructed in a variety of ways, including reinforced mortared cinder blocks, stacked slab concrete, concrete or cinder blocks with open rear faces that are set on top of each other at slight incline and filled with soil (i.e., Keystone block walls), or larger concrete bins that are backfilled with soil and have their front edge planted with vines. These walls provide good shear resistance and slope support, and can be designed to be somewhat flexible, however they deflect flows more than most of the other techniques listed here, and are very difficult to completely vegetate and disguise. *This technique has very limited applicability in the SLO Creek watershed for environmental reasons, but could be considered where top of bank land constraints and channel capacity limitations require near vertical walls be used.*

- **Live Rock Wall**. Rocks can be end dumped on a stream bank, or they can be carefully hand crafted into aesthetic walls that can support vegetation (***Figure 6-10***). While such walls are very structural, they also have a role in restoration. In constricted situations, a hand-laid rock wall can be built to provide a stable bank. Concrete rubble pieces can sometimes be used in place of rock and still look similar to a rock wall, as in the Mission Plaza area. The spaces between the rocks or rubble pieces can be planted with cuttings as the wall is constructed. This sort of wall is referred to as rock work, as opposed to rip-rap. This approach preserves bank top land allowing for nearly vertical banks. *Typically this is used when bank top encroachment is severe and valuable property or structures are threatened.*

- **Post and Wire Fencing** is a continuous single or double row of pilings with a facing of woven wire (***Figure 6-11***). The pilings (either wood or metal posts) are typically placed six to eight feet apart, with maximum heights of 1.8 meters (6 feet). The posts are inserted in pre-drilled holes or are driven in to a depth of at least half their height, refusal, and/or below anticipated scour depth. Live brush cuttings, inter-layered with rock and soil can be laid behind the post-and-wire fencing. Vertical slopes to six feet in height can be constructed using this technique. The structure can have a significant affect on channel flow resistance, which needs to be carefully considered in flood prone areas. They are also susceptible to damage from woody debris carried in high flows. *This technique has limited applicability in the SLO area.*

- **Planted Gabion Baskets** consist of rectangular containers prefabricated from twisted heavy gauge galvanized steel wire (***Figure 6-12***). The empty baskets are placed in position on a prepared bed, wired to adjacent baskets, and filled with rock. The baskets can be planted by placing live branches on a layer of soil between successive baskets. It is very important to toe in the bottom basket at least the depth of anticipated scour, usually at least one basket in depth. Gabions could be used on the project site but there cost is typically more then some of the other options and are usually reserved when property and structures must be protected. *This technique is often difficult to permit and is relatively expensive. Unplanted gabion baskets normally will not be considered in the SLO watershed, except for at very small and constrained sites.*

- **Reinforced Concrete.** Reinforced concrete may be used selectively to armor seriously failing sections of streambanks. Structural elements include walls, bulkheads, and bank linings. Positive drainage behind these structures is required to relieve uplift pressures. These systems are inflexible and prove to fail under lateral forces, or when undercut by channel bed erosion. *Generally the use of reinforced concrete channel lining should be avoided or used in short segments where other methods cannot be considered because of lack of space or other reasons.*

- **Modular Pre-cast Units.** Interlocking modular pre-cast units of different sizes, shapes, heights and depths have been developed for a wide variety of applications. These serve in the same manner as gabions. Units with void areas can allow the establishment of vegetation. They provide verticality in tight areas as well as durability. Many types are available with textured surfaces. They also act as gravity retaining walls. They should be designed and installed in accordance with the manufacturer's recommendations.

6.6.3 In-Stream Structures

The following in-stream features can provide some protection to eroding streambanks. In addition to aquatic habitat enhancement. However, because their effects are somewhat unpredictable and because they are primarily intended to increase aquatic habitat value, they were not included in the above sections. A careful hydraulic and geomorphic analysis should be conducted prior to their use. These techniques should be incorporated into some projects.

The following are additional reference for the design of in-stream habitat structures:

Flossi, G., S. Downie, J. Hopelain, M. Bird, R. Coey, and B. Collins, 1998. California Salmonid Stream Restoration Manual State of Calif. Dept. of Fish and Game, Sacramento, CA.

Hunt, R.L., (1993) Trout Stream Therapy, University of Wisconsin Press, Madison, Wisconsin.

Hunter, C., (1991) Better Trout Habitat: A Guide to Stream Restoration and Management, Island Press, Covelo, California.

Riley, A., (1998) Restoring Streams In Cities: A Guide for Planners, Policymakers and Citizens.

Newbury, R., M. Gaboury, and C. Watson, (1999) Field Manual of Urban Stream Restoration Conservation Technology Information Center, W. Lafayette, Indiana.

- **Flow deflectors/Rock Spurs** consist of rocks and rock-log combinations arranged diagonally from the streambanks and protruding into the stream channel (***Figure 6-13***). They are placed and oriented so as to redirect the stream flow away from the failing bank to strike the opposite bank or bar and promote scour and low-flow meander. The pools created in this manner provide important rearing habitat and cover for fish. It may be necessary to protect both the repair site and the opposite bank with a revetment or armoring device. *These devices must be used carefully in urban settings because the redirected flow can destabilize downstream embankments.*

- **Log, rootwad, and boulder revetments** are composed of logs, rootwads, and large boulders selectively placed in and on streambanks (***Figure 6-14***). Generally boulders and cables are used to anchor the woody debris. These structures provide excellent hiding habitat and local scour holes, but can deflect flow at the bank toe and undermine bank stability. A vegetated geogrid can be constructed atop the rootwad-boulder revetment. If large flat-oblong rocks are carefully selected and placed at the base of the slope, along with cabled logs, slopes as steep as 1.25H:1V can be constructed. As with all bank stabilization structures, keying into the toe and channel bank are critical to their performance. This technique requires considerable contractor experience, skill, and care to construct, and there is a high degree of uncertainty in the performance and hydraulic impacts of these structures. Because of design and engineering uncertainties, these structures are best utilized in natural areas that do not have high value structures at bank top.

- **Boulder or Grouted Rock Check Dams.** Reductions in channel slope to reduce velocities can be made at a single point using a check dam/drop structure or over a short distance by using large boulders to create riffle-pool sequences (***Figure 6-15***). There are a number of key elements in the construction of these structures. The drop in elevation should be small, both to allow fish passage and to reduce the scour potential at the base of the structure. Drops of less than 0.5 meter are recommended. On the downstream side of the drop, a plunge pool should be constructed to dissipate energy and provide fish resting areas. The pool should be constructed by excavating the channel bottom, or by constructing a second small structure approximately 2.5 to three meters downstream. The ends of the structure must be keyed into the banks to prevent end-scour. These areas can be replanted with willow poles to provide additional stability. For the loose boulder grade control structure, basic stability is achieved by appropriate rock sizing. Added stability can be achieved by grouting the rock to a reinforced concrete foundation below the scour depth in very high velocity reaches.

  Behind each grade control structure, gravel, cobble and small boulders can be strategically placed to create fish habitat. Rooted aquatic vegetation will generally colonize the margins of the structure. These emergent plants will provide some shade and valuable cover for fish, and aquatic organisms.

  Boulder Clusters and Rock Vortex Weirs. Boulder clusters (***Figure 6-16***) can be used to redirect stream flow and reduce flow velocity. Typically, a boulder cluster consists of three or more boulders, with the largest placed upstream to protect the smaller boulders from washing out at high flows. The boulders should be partially buried using a footer rock. Generally flat-oblong (not round) rocks are selected for use. The area around and under the boulders provides fish with escape cover. It may be desirable to also create fast moving water by placing boulders in a cluster to constrict flow (rock vortex weir), and strategically place clean gravels and cobbles. Most often boulder clusters are used to provide compensation or mitigation for project elements that fill pools. It may be desirable to create fast water areas by placing boulder clusters to constrict stream flow and, where needed, by adding gravel and cobble downstream of the constriction. Such areas are important for insect production and water oxygenation. Downstream boulders create plunge pools and scour pools may develop and provide fish resting and feeding areas. The best fisheries habitat is provided where overhanging banks provide cover and bank slope vegetation shades the stream.

- **Lunker structures** are designed to provide artificial overhanging shade and protection while serving to stabilize the toe of a streambanks (***Figure 6-17***). They are constructed from wood or plastic lumber and resemble a sort of rough, large coffee table in appearance. They are preconstructed, set in place at the toe of a stream along the outside of a bend, and filled around and on-top with planted rock or geogrids. Placement is critical to insure that they stay submerged and provide critical summer low flow habitat, and do not become filled with sediment. These structures are also used to compensate for lost aquatic habitat, or as part of a stream enhancement project.

6.7 Procedures for Designing Rock Slope Protection (RSP)

The following procedure was adapted from State of California, Department of Transportation "California Bank and Shore Rock Slope Protection Design" Final Report # FHWA-CA-TL-95-10, October 2000. An extensive discussion on the development of the design procedure can be found in this reference.

6.7.1 Collect River/Stream Data

Data are needed to determine average stream velocity and whether the stream is flowing parallel-to or impinging-on the banks. Obtain records of flow rates, velocities, and stages, or estimate values and try to field-verify them (next step). Obtain ground and aerial photographs, maps, and as-built contract plans of existing, adjacent, and nearby bank protection, which have RSP or alternative revetment materials.

6.7.2 Inspect Site

A field visit to the site is required. Determine the site hydrology, existing slope angles and bank soil types, presence of springs and seeps, and what materials and conditions are likely for imported borrow. Estimate channel and nearby bank roughness. Confirm the direction of flow, angles of stream flow at various stages (flow depths), and flow rate and velocity estimates which were made in section 1-A. Obtain stream cross sections, where and when feasible, to verify flow rates and velocities at various stages. Interview local maintenance people and residents. Try to determine the number of events that overtopped banks and the stages that may have flooded roads and properties. Obtain information on the extent of damages and any temporary repairs made during flood events. Temporary repairs might have to be reconstructed. Data on nearby RSP sites is useful; those sites should be field-reviewed and reevaluated after significant events. Consult with a geotechnical engineer about slope stability. Contact wardens, agency biologists, and engineers of agencies that require permits or agreements. The permit requirements are discussed in the Stream Maintenance and Management Manual. Additional considerations include: fish passage, fish habitat, restricted times to work due to life cycles of local biota ("construction windows"), endangered plant or animal species, revegetation requirements, and aesthetics.

6.7.3 Determine Minimum Stone Weight

Equation 6-3

$$W = \frac{0.055\ V^6\ SG}{(SG-1)\ 3\ \sin^3 (r-a)^\circ}$$

W = theoretical **minimum rock mass (size or weight)** which resists forces of flowing water and remains stable on slope of stream or river bank, kg.
V = velocity to which bank is exposed, (m/s)
•*For PARALLEL flow multiply average channel velocity by 0.67*
•*For IMPINGING flow multiply average channel velocity by 1.33*
SG = specific gravity of the rock.
r = 70° (for randomly placed rubble, a constant).
a = outside slope face angle with horizontal, (DEGREES)

In profile, the lower elevation limit of riverbank RSP is based on expected scour (determined by experience, measurements, or scour equations). The upper elevation limit is based on design high water, although it may be set higher.

Review the inputs of **Equation 6-3**. Was average stream velocity decreased for parallel flow or increased for impinging flow? Estimate whether parallel flow is likely to persist in the future. Do not arbitrarily raise velocities to higher values, because **Equation 6-3** is very sensitive to velocity. If you must be conservative, wait until **Section 6.6.4**, where you select the outside layer RSP-*Class*. For preliminary calculations, use 2.65 as the value of specific gravity. Consult with a materials engineer and determine likely sources of rock and values of specific gravity, which are based on material tests. In California practice, the minimum specific gravity is 2.50. Other required rock properties and tests are shown in Appendix B page B-2, of section 72-2.02 of the 1995 *Caltrans Standard Specification*s. A guideline for the maximum outside slope face angle of the RSP with the horizontal is 33.69 degrees, that is, 1.0 vertical to 1.5 horizontal (1V:1.5H). The outside layer of rocks must interlock and must be stable in flowing water. The underlying bank must be stable during construction, therefore consult with a geotechnical engineer and confirm that the proposed angle of the underlying bank slope is acceptable. The outside slope face and underlying bank slope angles do not necessarily have to be the same.

6.7.4 Determine RSP-Class of Outside Layer

Determine the RSP-*Class* of the outside layer of the revetment, using ***Table 6-3.***

Before proceeding, an explanation of the Caltrans standard RSP gradations and terminology is needed. For this discussion see ***Table 6-3***, which is similar to page 72-1Section 72-2.02 Materials of the 1995 Caltrans *Standard Specification*s. All the standard gradations are named **RSP-Classe**s. ***Table 6-3*** is divided into two sections with a bold dashed vertical line, which separates two construction methods of placing rock. "Method A" is for larger RSP-Classes, and "Method B" is for smaller RSP-Classes. Column headings listed immediately above the bold horizontal line are SI (metric) names of RSP-Classes, and US Customary names are listed above the SI (metric) names. RSP-Classes are used on typical cross sections and plans and pay item descriptions in the engineer's estimate. In SI (metric) units they are: *8T, 4T, 2T, 1T, 1/2T, 1/4T, Light, Facing, Backing No. 1, Backing No. 2, and Backing No.* 3.

The label for each horizontal row is a STANDARD Rock SIZE or Rock Mass or Rock WEIGHT. To clarify that they are row labels, the STANDARD Rock SIZES are separated from the gradations by a bold vertical line. Almost all RSP-Classes are named by the "50-100" percent STANDARD Rock SIZE, also called W50.

The gradations in ***Table 6-2*** were adopted by the California Division of Highways in the late 1950's; they are similar to gradations which were recommended by AASHO (American Association of State Highway Officials). Although the table is labeled in bold print as **PERCENTAGE LARGER THAN**, gradations are sometimes misquoted as percentage passing or percentage smaller than. To help understand the table, look at *METHOD A Placement, 1T RSP-Clas*s. "95-100" percent means nearly all the rocks are heavier than 450 kg and lighter than 1.8 tonne, the maximum STANDARD Rock SIZE of the *1T RSP-Clas*s. The "95" allows 5 percent of the rocks to be lighter than 450 kg, for breakage during production at the quarry, transport, or placement at the site. "50-100" percent means at least half the individual rocks must be heavier than 900 kg and lighter than 1.8 tonne. "0-5" allows 5 percent of the rocks to be heavier than 1.8 ton, and with the slope tolerance dimension of 300 mm, not too many out-of-spec oversized rocks should show up on a job. Nowhere in the table or footnote does it state that "all rocks must be the same weight as the 50-100 standard rock weight."

Sometimes quarries produce what is called "Caltrans spec rock." That is, each rock is nearly the same size as the "50-100" percent standard rock size **(W50)** of the RSP-Class, such that there is no visible range of rock sizes. Table 11-1 does not clearly exclude same-sized rocks in an RSP-Class. When a quarry consistently produces nearly same-sized rocks for standard RSP-Classes, consider multiplying the **D50** by 2 (effective diameter of the "50-100" percent standard rock size of the RSP-Class), for minimum layer thickness. This assures adequate rock interlock, which is required for a stable RSP facility. **Section 6.5.6** presents more information about thickness.

To determine the RSP-Class of the outside layer, enter ***Table 6-3*** at the left. Select the closest STANDARD Rock SIZE greater than W, the minimum rock weight calculated in this section. Trace horizontally to the right and find the "50-100" (or “25-75") table entry. Finally, trace upward vertically to the column heading and simply read the RSP-Class. Use this as the "first trial" RSP-Class of the outside layer of bank protection; it may also become the "final selection."

With historical, site-specific knowledge and engineering judgment of existing and expected field conditions, decide whether the "first trial" RSP-Class should be lighter or heavier for the "final selection." Some considerations are:

a) Recreational users can move rocks lighter than 90 kilograms. There have been reports of rocks being stolen and used in home landscaping projects. Therefore, if the project is in a populated area or where there is high recreational use, and if **Equation 6-3** ultimately gives an RSP-Class smaller than *Light* for the outside layer, then consider specifying *Light*.

b) If sections of RSP have sloughed into the creek where the road closely follows the river, check design notes and nearby RSP site histories, which might reveal that parallel flow was assumed. By field-reviewing the site at low and moderate stages, you may note meandering flows that impinge and attack the toe of RSP. Meanders can be caused by migrating gravel bars and deposited debris during floods. Recalculate the minimum W in **Equation 6-3** using an impinging velocity, determine the RSP-Class of the outside layer, and compare it to the existing RSP-Class. Consider a heavier Class or extending the toe of the revetment.

Table 6-3
Guide for Determining RSP - Class of Outside Layer

STANDARD Rock SIZE or Rock MASS or Rock WEIGHT		GRADING OF ROCK SLOPE PROTECTION **PERCENTAGE LARGER THAN**											
		RSP-Classes [A]											
		Method A Placement: Larger RSP					Method B Placement: smaller RSP						
		RSP-Classes other than Backing									Backing No.		
US unit		8 ton	4 ton	2 ton	1 ton	½ ton	1 ton	½ ton	1/4 ton	Light	Facing 1[B]	2	3
	SI unit	8 T	4 T	2 T	1 T	½ T	1 T	½ T	1/4 T	Light	Facing 1[B]	2 T	3 T
16 ton	14.5 tonne	0-5											
8 ton	7.25 tonne	50-100	0-5										
4 ton	3.6 tonne	95-100	50-100	0-5									
2 ton	1.8 tonne		95-100	50-100	0-5		0-5						
1 ton	900 kg			95-100	50-100	0-5	50-100	0-5					
½ ton	450 kg				95-100	50-100	---	50-100	0-5				
1/4 ton	220 kg					95-100	95-100	----	50-100	0-5			
200 lb	90 kg							95-100	----	50-100	0-5		
75 lb	34 kg								95-100	----	50-100	0-5	

STANDARD Rock SIZE or Rock MASS or Rock WEIGHT		GRADING OF ROCK SLOPE PROTECTION **PERCENTAGE LARGER THAN**											
		RSP-Classes [A]											
		Method A Placement: Larger RSP					Method B Placement: smaller RSP						
		RSP-Classes other than Backing									Backing No.		
25 lb	11 kg									95-100	90-100	25-75	0-5
5 lb	2.2 kg											90-100	25-75
1 lb	0.4 kg												90-100

[A] US customary names (units) of RSP-Classes listed above SI names, Example US is “2 ton” metric is “2 T”.
[B] “Facing” has same gradation as “Backing No. 1". To conserve space “Facing” is not shown.

Example for determining RSP-Class of outside layer. By using Equation 1, if the calculated W=135 kg (minimum stable rock size):

1. Enter table at left and select closest value of STANDARD Rock SIZE which is greater than calculated W, in this case 220 kg
2. Trace to right and locate “50-100" entry
3. Trace upward and read column heading “1/4 T”, then 1/4 T is first trial RSP-Class.

6.7.5 Determine the Required Layers of RSP

Inexperienced designers sometimes use ***Table 6-3*** and specify all the RSP-Classes between the "final selection" outside RSP layer and Backing No. 3. To avoid this pitfall, use ***Table 6-4***, **California Layered RS**P. Standard designs include RSP-fabric, Backing Class, Inner, and Outside layers of RSP as shown. In ***Table 6-4***, in conformance with filtration theory, from the bank to the stream, each layer was designed progressively larger, so an inner layer will not pass through voids of the next layer. The thickness of the entire cross section is reduced and less costly when RSP-fabric replaces Backing No. 3. Do not arbitrarily eliminate RSP-fabric. If you do not use RSP-fabric, then 230 mm of *Backing No. 3* is normally required as the initial "filter-separator" layer, and it is placed directly on the bank to be protected. If *Backing No. 3* is rounded, river-run material, then the steepest allowable slope angle should be 1V:2.5H, contrary to the recommended 1V:2H of the Caltrans *Standard Specification*s.

An example using RSP-fabric is: *Type B RSP-fabric* is placed directly on the bank as the initial "filter-separator" material, the inner layer is *Light,* and the outside layer is *1*T. Notice that in ***Table 6-4***, when the outside layer is 1T or larger there is more than one possible design for inner layers. Each design satisfies filtration theory, that is, underlying layers are retained. Rock availability and/or cost of producing one design versus another may determine which RSP-classes are selected as inner layers. Or on another part of a project there may already be a specified inner RSP-class, and rather than introducing another inner RSP-class, use the one that is already specified.

Table 6-4 California Layered RSP SI metric (US customary values shown for OUTSIDE LAYER only).			
OUTSIDE LAYER RSP-CLASS*	**INNER LAYERS RSP-CLASS***	**BACKING CLASS No.***	**RSP-FABRIC TYPE****
8 T (8 ton)	2 T over ½ T	1	B
8 T (8 ton)	1 T over 1/4 T	1 or 2	B
4 T (4 ton)	½ T	1	B
4 T (4 ton)	1 T over 1/4 T	1 or 2	B
2 T (2 ton)	½ T	1	B
2 T (2 ton)	1/4 T	1 or 2	B
1 T (1 ton)	LIGHT	NONE	B
1 T (1 ton)	1/4 T	1 or 2	B
½ T (½ ton)	NONE	1	B
1/4 T (1/4 ton)	NONE	1 or 2	A
LIGHT (LIGHT)	NONE	NONE	A
Backing No. 1*** (Backing No. 1)	NONE	NONE	A

* Rock grading and quality requirements per Section 72-2.02 Materials of the Caltrans Standard Specifications.

** RSP-fabric Type of geotextile and quality requirements per Section 88-1.04 Rock Slope Protection Fabric of the Caltrans Standard Specifications. Type A RSP-fabric has lighter mass per unit area and it also has lower toughness (tensile x elongation, both at break) than Type B RSP-fabric. Both types require minimum permittivity of 0.5 per second.

*** "Facing" RSP-Class has same gradation as Backing No. 1.

Material property values were selected for the RSP-fabric in Section 88-1.04 of the Caltrans *Standard Specification*s, by assuming that construction inspectors will limit the maximum height of rockfall during placement to about 1 meter. End dumping of rock down embankments is not recommended, because rocks will damage and dislodge the RSP-fabric and the rock sizes will segregate.

A layer of *Backing No. 1* or *No. 2* is the first layer of rock, which is placed directly on RSP-fabric, unless there is only *Light* or *Facin*g. Backing keeps the RSP-fabric in contact with bank soil, thereby preventing soil movement and loss of fines by piping and erosion through overlapped RSP-fabric, which can ultimately lead to failure. *Light* or *Facing* is the largest RSP-Class, which should be placed directly on RSP-fabrics. When the revetment cross-section includes RSP-Classes greater than light, inner layers of RSP are required. When the cross section of the revetment includes any RSP-Class greater than *1/4* T, then *TYPE B RSP-fabric* is required. Placing a layer of sand to protect RSP-fabric from damage is normally not needed. Caltrans specifies RSP-fabrics to be tough enough to withstand normal construction practices like rockfall of 1 meter or less.

6.7.6 Determine the Thickness of the RSP Revetment

First determine t, the minimum layer thickness. Sum each minimum layer thickness to get the total thickness of the revetment. In the Engineer's estimate, for each RSP-Class, a method of placement is specified: either Method A or Method B. Typically, Method A is used for large RSP-Classes, which require individual placement by equipment to achieve "3- point bearing" (no wobbling) on adjacent rocks. Method B, also called "dumped RSP" does not mean that rock can be dumped from the top to the bottom of long embankments. Placing rock by Method B means that rock is dumped near its planned location, then machinery works the rock to its final position. When feasible, work normally progresses from lower to higher elevations to control thickness and size segregation.

Table 6-5 provides guidance for the minimum layer thickness. First an effective diameter **D50** was calculated with assumptions: specific gravity is 2.65 and rock shape factor is spherical. This does not mean the rocks are actually spheres. Use the formula for the volume of a sphere to calculate **D50**, but first select **W50**, the "50-100" percent standard rock weight and use the "definition" formula, Volume is Weight divided by Specific Weight. In SI units:

cubic meters = kilograms / [1,000 kg/ cubic meter) x specific gravity].

For Method A placement, the resulting **D50's** were multiplied by 1.5, which is a reasonable value to assure interlock of rocks within the same layer, and for interlock with subsequent layers. For Method B Classes *Backing No. 1* through *1*T, the **D50's** were multiplied by 1.875. The 25 percent increase accounts for looser placement by spreading and for placing in flowing water. The factors 1.5 and 1.875 are empirical and usually have worked well in CA. Local experience or data of flume studies could support factors other than 1.5 or 1.875 for layer thicknesses on a particular job.

Table 6.5-3. Minimum Layer Thickness SI metric (US customary)		
RSP - Class Layer	Method of Placement	Minimum Thickness
8 T (8 ton)	A	2.60 meters (8.5 feet)
4 T (4 ton)	A	2.07 metes (6.8 feet)
2 T (2 ton)	A	1.65 meters (5.4 feet)
1 T (1 ton)	A	1.31 meters (4.3 feet)
½ T (½ ton)	A	1.04 meters (3.4 feet)
1 T (1 ton)	B	1.65 meters (5.4 feet)
½ T (½ ton)	B	1.31 meters (4.3 feet)
1/4 T (1/4 ton)	B	1.00 meters (3.3 feet)
Light	B	760 millimeters (2.5 feet)
Facing	B	550 millimeters (1.8 feet)
Backing No. 1	B	550 millimeters (1.8 feet)
Backing No. 2	B	380 millimeters (1.25 feet)
Backing No. 3	B	230 millimeters (0.75 feet)

For total thickness, add each layer thickness. Use zero thickness for the RSP-fabric. Before adopting values in ***Table 6.5-3*,** consult with a materials engineer about rock sources, quality, shapes, and specific gravity. Calculate new thickness values if the shape factor is not spherical and specific gravity is not reasonably close to 2.65.

6.7.7 Review Hydraulic Calculations at Site With RSP and Possibility of Vegetation .

This step of the layered design process is required to help assure future success of the revetment under changed channel dimensions, roughness coefficients, and other permit/agreement requirements. Examples are: filling voids among RSP with soil and/or covering RSP with soil then planting local species, and/or enhancing fish habitat by placing large-sized rock along the toe. Discuss site hydraulics with people of permit agencies and feasible revegetation efforts. Historically, sites with no prior vegetation are usually not revegetated, especially when subjected to scouring velocities or high wave attack.

SECTION 7.0

DESIGN OF CONDUITS, CULVERTS, AND OPEN CHANNELS FOR MINOR WATERWAYS

This section outlines the design criteria for closed conduits, and for minor waterways including roadside ditches that have a design discharge of less than 1.0 cubic meters per second (36 cubic feet per second). Minor waterways have a catchment area of less than 2.6-km^2 (1-mile ^{2}) and shall be designed for a minimum storm recurrence interval of years, with 0.3-m (1-ft.) of freeboard (**Section 5.2**).

This section also addresses the hydraulic analysis and design of runoff that drains onto and across improved surfaces such as streets, residential and commercial areas and parking lots and then into storm drains via drop or curb inlets. The storm drainage is then conveyed into a natural or improved open channel.

The design discharge and street flow hydraulics are to be determined following the procedures contained in the Federal Highway Administration's *Urban Drainage Design Manual, HEC-22* (FHWA 2001, 2nd edition). This document includes procedures for determining runoff from paved areas, gutter flow, and the hydraulics of drop inlets and curb inlets, storm drains and culverts, pump stations, and minor open channel flow using normal depth methods of analysis. In some situations, a backwater hydraulic model should be used in the hydraulic analysis. The FHWA Design Manual, HEC-22, is available online at http://fhwa.dot.gov/bridge/hec22.pdf.

Street and their associated underground drainage system must be designed so that they convey the 100-year runoff such that the water surface elevation is at least 1-foot below the finish floor of adjacent structures, in conformance with the provisions of ***Section 3.5***.

As part of this analysis, the engineer shall consider the overall safety of adjacent developments. This process includes understanding what happens for events larger than the 100-year, and also what happens if critical drainage devices become blocked with debris. Drainage overflow points or secondary outlets that anticipate such occurrences shall be designed into the overall drainage system.

All stormwater system elements (including, but not limited to conveyance systems, stormwater detention facilities, and vegetated corridors) shall be designed and constructed in accordance with all applicable rules and regulations of the City and County stated in this Manual. Any interpretations, must be consistent with applicable referenced technical guidance manuals, and with all applicable federal, state and local statues and rules.

The designer of the storm drain system will have to use good professional judgment when dealing with the constraints and conflicts with existing infrastructure. When the design engineers have to deviate from the standards and criteria contained in the Manual, they should contact the City or County as soon as possible to explain the situation and come to an agreement on the solution.

7.1 Extension of Public Storm Drainage Systems

Public storm drainage systems shall be extended to the most distant upstream parcel boundary(s) to accommodate current and future storm flows entering the property, unless otherwise approved by the City or County. The maximum length of gutter flow prior to interception to storm drainage system is 122 meters (400 feet). Except as otherwise provided, the extension of the public stormwater systems to serve any parcel or tract of land shall be done by and at the expense of the Property Owner or applicant. The City or County may require that a storm pipeline that serves or may serve more than one property be a public system.

7.2 Design

7.2.1 Channel and Conduit Capacity

Special provisions shall be made by the project proponent for any new building development or redevelopment project within a drainage system to insure that the inlet flow line elevations and the capacity of the drainage system is such that it may be extended to serve and to properly handle the entire drainage basin at the time of ultimate development. This is to include the entire upstream portion and the portion of the basin outside the development, regardless of existing conditions. The hydrologic analysis shall be consistent with ***Section 4.0 Hydrology and Hydraulics***. The engineer may use various computer models or formulas for the hydrograph analysis but the City or County may verify the design flows, and volumes. Modifications to the existing on-site storm drainage facilities shall not restrict flows creating backwater onto off-site property to levels greater than the existing situation unless approved by the impacted off-site property owners.

- The conveyance system shall be designed to convey and contain at least the peak runoff for the 10-year design storm. Design surcharge in pipe systems shall not be allowed if it will cause flooding in portions of a habitable structure, including below-floor crawl spaces.

- The 10-year design shall be supplemented with an overland conveyance component demonstrating how a 100-year event will be accommodated. This overland component shall not be allowed to flow through or inundate an existing building.

7.2.2 Channel Alignment and Channel Stability

The diversion of minor waterways will be allowed only within the limits of the proposed improvement or project development site. All natural drainage must leave the improved area at its original location and with approximately the same discharge velocity as existed prior to development unless a special agreement indemnifying and approved by the City or County, as appropriate, has been executed with the adjoining property owners. The downstream waterway must be shown to be stable and consistent with these guidelines and criteria under proposed conditions. This will normally require that the project proponent or developer complete a hydrologic and hydraulic investigation using the procedures contained in this Design Manual.

7.2.3 Storm Drain Location and Alignment

The general location for storm drainage lines shall be 3.6 m (12 ft) northerly or westerly of the centerline of a street. Within the City of San Luis Obispo, storm drain placement shall comply with **City Standard 6010**.

Other general requirements for storm drains are as follows:

- Storm drainage lines are to be parallel with the centerline of streets unless impracticable. The designer should avoid meandering, offsetting, and unnecessary angular changes (none to exceed 90°).

- Provide junctions between converging lines in such a manner as will minimize losses and utilize available velocity head, and locate the centerlines of the influent and effluent lines so that they will be approximately in the same plane and be as nearly as possible parallel to the resultant vector of the converging lines.

- The vertical alignment shall be so designed to eliminate any ponding within the drainage system, other than where sump pumps are provided.

- Existing open ditches, paved channels, and swale flows shall be maintained as nearly as possible in their existing alignment.

Note: additional requirements for design, construction, and management of Major and Secondary Open Channel flows are presented in ***Section 2.2*** of this Design Manual

7.2.4 Design of Drainage Structures

The design and construction of drainage structures and special drainage items shall conform to the City's Standard Plans and Specifications and to the designs contained in these this Manual, unless otherwise noted. Special care must be taken to insure that all drainage structures and pipe are designed at such a capacity that the drainage system may be extended or enlarged to serve the entire drainage basin at ultimate development. The Rational Method determined flow, or flow determined using the SLO/Zone 9 hydrology model, as described in ***Section 4.0*** shall be indicated on the improvement plans at each drainage structure.

The following guidelines address the design of closed conduits.

7.2.4.1 Design of Closed Conduit Systems

Closed conduits (pipes) shall be of either cast-in-place or pre-cast reinforced concrete pipe or an approved equal.

- Mainline or trunk storm drainage pipes shall be 600-mm (24-inches)

- Minimum pipe diameter allowable on any secondary storm drain shall be 450 mm (18 in). A 380 mm (15 in) diameter pipe may be used for culverts of not over 6 m (20 ft) in length subject to the approval of the City Engineer or County Public Works Director. A lesser size may also be used for down drains on fill slopes if approved by the City Engineer or County Public Works Director.
- Minimum design velocity in closed conduits shall be 0.6 m/s (2 ft/s) when conduit is flowing to capacity and should not exceed 4.6 m/s (15 ft/s).
- Any drainage facility whose capacity is equal to or less than a 760 mm (30 in) pipe shall normally be carried in a closed conduit in all subdivisions of an average lot size of 1,860 m^2 (20,000 ft^2) or less.

7.2.5 Pipe Cover

Minimum pipe cover shall be in compliance with the following table unless the City or County approves an exception. Within the City of San Luis Obispo, minimum cover requirements shall also comply with **City Standard 6010**.

Pipe Material	Pipe Sizes- Min and Max Mm (in)	Pipe Class	Min. Cover Mm (in.)
RCP-Concrete Reinforced Pipe	450 to 1500 mm (18” to 60”)	CL III CL IV CL V	450 mm (18”) 300 mm (12”) 150 mm (16”)
IDP-Iron Ductile Pipe	450 to 1500mm (18 to 60”)	Class 250	150mm (6”)
AWWA C905 PVC Plastic (sewer/drain)	450 to 1200 mm (18” to 48”)	SDR-35	600mm (24”)
HDPE High Density Polyethylene Pipe	450 to 1200mm (18 to 48”)	SDR-9	300 mm (12”)
Pipe material not allowed			
CMP-Corrugated Metal Pipe			
ACP-Asbestos Concrete Pipe			
ABS- Plastic Pipe			

Minimum cover in paved and unpaved street section is 900 mm (36”) per City Standard 6010

In paved areas, pipe cover shall be measured from the bottom of the sub-base to the upper surface of the pipe barrel. In pavement areas, the pipe bell shall not intrude into the sub-base. In areas without pavement, pipe cover shall be measured from finish grade to the upper surface of the pipe barrel.

At locations where the general minimum cover requirements cannot feasibly be obtained, the conduit shall be either encased in concrete or provided with a concrete cover or protected by other methods as approved by the City Engineer of County Public Works Director for each individual circumstance.

7.2.6 Manholes

- Cast in-place manholes with pre-cast risers shall be used wherever feasible. Within the City of San Luis Obispo, **City Standards 3510 and 3520** will apply. When cases arise where special manholes or junction boxes are required, the City Engineer or County Public Works Director shall approve the design. **City Standard 3530** is the standard for pre-cast concrete manholes.

- Manholes shall be located at junction points, changes in gradient and changes in conduit size. On curved pipes with radii of 60 m (200 ft) to 120 m (400 ft), manholes shall be placed at the BC or EC of the curve and on 90-m (300-ft) maximum intervals along the curve. On curves with radii exceeding 120 m (400 feet), manholes shall be placed at the BC or EC of the curve and on 120 m (400-ft) maximum intervals along the curve for pipes 600 mm (24 in) and less in diameter and 150 m (500 ft) maximum intervals along the curve for pipes 600 mm (24 in) and less in diameter and 150-m (500-ft) maximum intervals along the curve for pipes greater than 600 mm (24 in) in diameter. Curves with radii less than 60 m (200 ft) will be handled on an individual basis.

- Spacing of manholes or inlets, of such size as to be enterable for maintenance~~,~~ shall not exceed 120 m (500 ft) for drains 600 mm (24 in) and smaller in diameter and 180 m (600 ft) for pipes greater than 600 mm (24 in) in diameter, except under special approved conditions. The spacing of manholes shall be nearly equal wherever possible.

- All manholes or junction boxes, entry to which does not fall in the gutter line, must have standard 600 mm (24 in) diameter manhole covers.

7.2.7 Inlets and Catch Basins

- Gutter inlets shall be in accordance with the types shown on **City Standards 3320, 3330, 3340, 3350, and 3360**; **State Standard Drawings C-3 and C-4** or other approved special inlets. **State Standard Drawing D-72-9** may be used for extended curb opening inlets.

- Inlets shall be spaced so that gutter flow does not exceed a depth of 152-mm (6-inches) at the face of the curb for a 10-year storm and so that a 100-year storm will not cause any damage and can be contained within the right of way.

- Standard Catch Basin System: All catch basins shall be sumped. The main storm line shall not pass through any catch basins or sumped manholes unless approved by the City Engineer or County Public Works Director. No more than three catch basins may be connected in series before connecting to the main storm line. A ditch inlet or field inlet may be connected directly to the end of the main storm line.

- Unsumped Catch Basins: Unsumped catch basins are not allowed unless approved by the City Engineer or County Public Works Director. If an unsumped catch basin is required, a sumped manhole should be constructed below the unsumped catch basin before the flow enters the main storm line. The main storm line may not pass through the catch basins or sumped manhole.

- Grates shall be adequate for **City Standards 3320, 3330, and 3340 and State of California H-5-20** traffic loading.

7.2.8 Junction Boxes

- The use of junction boxes within the City of San Luis Obispo is to be discouraged and only allowed upon approval of the City Engineer.

- Boxes shall be constructed of Class "A" reinforced Portland cement concrete or fabricated from reinforced concrete pipe section where size limitations permit.

- Minimum wall thickness for poured-in-place reinforced concrete junction boxes shall be 150 mm (6 in).

- The inside dimension of junctions boxes shall be such as to provide a minimum of 75 mm (3 in) clearance on the outside diameter of the largest outfall pipe.

- All junction boxes shall have the standard 600 mm (24 in) manhole cover. (Phoenix P1090, Pinkerton A640, or approved equal)

7.2.9 Gutter flow, drop inlets, cross gutters, and sidewalk underdrains

- Design depth of flow in gutters shall not exceed the top of a 150 mm (6-in) curb or 200-mm (8-in) curb for the 10-year flow. Where the discharge gutter capacity for the 10-year flow is exceeded, an underground storm drain or other facilities shall be provided to convey the excess flow.

- Drop inlets shall be spaced such that gutter flow does not exceed a depth of 150 mm (6-in) at the face of the curb for a 10-year storm and so that the 100-year storm will not cause any damage and can be contained within the right-of-way.

- Cross gutters will only be permitted at intersections. Cross gutters are to be avoided wherever possible. They will not be allowed on arterial, collectors, bus routes or cross traffic local streets.

- Drop inlet, gutters, and sidewalk underdrains shall be in accordance with the types shown on City Standards 4310,4320, 3410, 3415 & 3420.

7.2.10 Hydraulic Gradient

The hydraulic grade line shall be a minimum of 150-mm (6 in) below the elevation of inlet grates and manhole covers of all structures.

7.3 Design of Culverts

7.3.1 Application

This section shall apply to culverts placed across streams and drainageways. For culverts with diameters of 900 mm (36 in) or greater or for driveway culverts which are part of a roadside ditch system, the County or City is the jurisdictional agency, and their road design standards shall apply.

7.3.2 Hydraulic Design of Culverts

Culverts will be designed to safely pass the flow per the catchment size standards indicated in **Section 5.2**.

- <u>Headwater</u>
  For new culverts 450 mm (18 in) in diameter or less, the maximum allowable design storm event headwater elevation (measured from the inlet invert) shall not exceed two times the pipe diameter or three times the pipe diameter with a seepage collar unless an exception is approved by the City or County.

- For new culverts larger than 450 mm (18 in) in diameter the maximum allowable design storm event headwater elevation (measured from the inlet invert) shall not exceed 1.5 times the pipe diameter unless an exception is approved by the City or County.

- The maximum headwater elevation of a design storm event for new culverts shall be at least 300 mm (12 in) lower than the road or parking lot travel way. Culverts with catch basins attached shall additionally maintain 150 mm (0.5 ft) of freeboard from top of grate or slotted inlet flow line.

- Culverts should be designed to the same flow rate as storm drains with a secondary overflow pathway for the 100-year event.

7.3.3 Inlet

For culverts 457 mm (18 in) in diameter and larger, the embankment around the culvert inlet shall be protected from erosion by lining around inlet with rock or other protection. The lining shall extend upstream from the culvert a minimum of five feet and shall be as high as the designed headwater elevation.

7.3.4 Outlets

For culverts 300 mm (12 in) in diameter and larger, the receiving channel of the outlet shall be protected from erosion by rock lining, bioengineering, or other City or County approved energy dissipater.

7.3.5 Culvert Analysis

The headwater depth for pipes under inlet or outlet control shall be determined using the nomographs continued in Section 4: Hydrology and Hydraulics, the Caltrans Hydraulics Manual, the FHWA's Hydraulic Design of Highway Culverts HDS5 (FHWA, 2001), or compatible computer modeling package (HEC-RAS, HY-8, Culvert Master, MacCulvert, or equivalent). Procedures for the design of energy dissipators are available in FHWA-HEC 145 (FHWA, 2001). The FHWA, HDS5 is available online at http://www.fhwa.dot.gov/bridge/hydpub.htm.

7.3.6 Cross Culverts

- Culverts shall be in accordance with the types indicated on **City Standards 4310 and 4320**.

- Culverts may be of reinforced concrete culvert pipe, or other materials meeting the requirements of these Standards and Specifications.

- A 10-year storm with no head.

- Waterways placed in closed conduit systems may be designed for full conduit capacity and pressure flow. The hydraulic entrance conditions at a closed conduit minor waterway shall be such that the 10-year discharge will have the specified freeboard in the upstream channel or waterway and that the 100-year discharge will have the specified freeboard in the upstream channel or waterway and that the 100-year discharge will be contained within the banks of the upstream waterway or drainage easement. The entrance to the closed conduit minor waterway may be submerged provided that the above criteria are satisfied.

- Culverts must be designed for adequate fish passage using the criteria of the California Department of Fish & Game (http://www.dfg.ca.gov/fishing/manual3.pdf) and the National

Marine Fisheries Service NMFS Southwest Region 2000, Guidelines for Salmonid Passage at Stream Crossings (http://swr.vcsd.edu/hcd/fdscg.pdf)

- Culvert profile shall be determined by the average profile of the channel for a minimum distance of 150 m (500 ft) each side of the installation.

7.3.7 Reinforced Concrete Box Culverts and Structural Plate Arch Culverts

All materials, designs, and construction shall conform to the requirements of the most current edition of the City of San Luis Obispo Standard Specifications, within the City of San Luis Obispo, or within the County of San Luis Obispo, the State Standard Specifications and State Standard Drawings unless otherwise specified by the Design Engineer and approved by the City Engineer or County Public Work Director.

7.3.8 Headwalls, Wingwalls, Endwalls, Trash Racks and Railings

- All headwalls, wingwalls and endwalls shall be considered individually by the City Engineer or County Public Works Direction and shall be, in general, designed in accordance with City Standard Specifications and Plans within the City of San Luis Obispo, or the State Standards outside of the City Limits.

- Trash racks shall be provided where in the opinion of the City Engineer or County Public Works Director they are necessary to prevent clogging of culverts and storm drains.

- Steel plate beam guardrail my be required by the City Engineer or County Public Works Direction at culverts, headwalls and box culverts and on steep side slopes. Handrails will be required if sidewalks are present. When so required, the railing shall be installed in accordance with State Standards and Specifications.

7.4 Design of Minor Waterways

All channel realignment, improvement, and culverts shall be shown on the improvement plans and shall conform to the requirements of the City of San Luis Obispo and /or County of San Luis Obispo Standard Specifications. No diversion to roadside ditches will be allowed from natural drainage courses.

Drainage facilities shall be so constructed and areas adjacent to channels so graded that side drainage will enter in a manner, which will prevent erosion within the rights of way. This will often require constructed side inlets and collector ditches to carry side flow to inlets.

7.4.1 Channel Lining and Protection

Minor waterways may be a natural watercourse, constructed channel, earthen channels, or a channel lined with the materials listed below (in order of preference), provided that the selected lining material is approved by the City Engineer or County Public Works Director for the particular channel reach and a permit has been obtained for use of the materials from the appropriate regulatory agencies:

- Low-growing for grass, which will form a thick, dense sod. The proposed grass mixture is to be submitted approval by the City Engineer or County Public Works Director.
- Rock slope protection facing class, Method B Placement.
- Concreted-rock slope protection facing class, Method B Placement.
- Sacked concrete slope protection.
- Concrete slope paving.
- Air-blown mortar.

7.4.2 Channel Velocities

- Minimum velocity for channels flowing full, with freeboard shall be 0.6 m/s (2ft/s).

- Maximum velocity shall be as follows:
  1. Earth channels not to exceed velocity that would cause erosion (maximum 1.5 m/s or 5 ft/s) for cohesive soils, or 3.3 ft/s for non-cohesive soils)

  2. Lined channels not to exceed 3 m/s (10 ft/s) or as approved by the City Engineer or County Public Works Director.

7.4.3 Freeboard and Overflow Easement

- Freeboard of at least 300 mm (1 ft) or 0.2 of the specific energy (whichever is greater) shall be provided at design capacity for all channels. Where linings are required, they shall extend to the full height of freeboard.

- For natural waterways, the design flow may be allowed in the natural overflow area if a drainage easement is provided, which will include the overflow area, and freeboard (as specified above) exists between the projected water surface elevation, and an adjacent ground surface.

7.4.4 Open Channels

- The side slopes for realigned channels shall not exceed 1:1 on any approved, lined portion and 2.5:1 on the unlined portions.

- For all intermediate channels, either realigned or natural, within an improvement, the following information shall be shown on improvement plans in addition to information previously indicated.
  - Typical sections.
  - Profile of the existing channel for a minimum of 150 m (500 ft) each side of the development in order to establish an average profile grade through the development.

7.4.5 Outfalls/Open Channel & Pipe Systems

- All drainage outfalls shall be shown both in plan and profile on the improvement plans for a distance of 300 m (1000 ft) or until a definite "daylight" condition is established.

- When improvements have more than one unit, the drainage outfall shall be shown as extending to the property boundary, and beyond if required, although it may not be constructed with the current unit development. All temporary outfalls shall be shown both in plan and profile on improvement plans.

Outfalls shall be above the mean low water (2-year flow) level unless the City or County approves an exception.

- All outfalls shall be provided with a rock splash pad or other approved erosion control measure. Rock protection at outfalls shall be designed in accordance with the guidelines in Section 6.0: Hydrology and Hydraulics, unless the City or County approves exceptions. Mechanisms, which reduce velocity prior to discharge from an outfall are encouraged.

- Engineered energy dissipators, including but not limited to, stilling basins, drop pools, hydraulic jump basins, baffled aprons, and bucket aprons, are required for outfalls with velocity at design flow greater than 10-feet per second. These shall be designed using published references such as Hydraulic Design of Energy Dissipators for Culverts and Channels published by the Federal Highway Administration of the United States Department of Transportation, the Caltrans Hydraulics Manual and others. Design reference shall be cited on the construction plan submittal.

7.4.6 Fencing

- Constructed channels with side slopes 5:1 or flatter need not be fenced.
- Natural channels need not be fenced, except where special hazards exist as defined by the City or County.
- For constructed channels, (not excepted from fencing) a 1.5-m (5-ft) high chain-link fabric with tension wire shall be installed on each side of the right-of-way. At all road

intersections, fencing shall prevent public access to channel or culvert, and 4.3-m (14-ft) wide chain-link drive gates shall be provided at all points of access to maintenance ways, or to channels not requiring maintenance ways. Chain link fence should be vinyl coated or as required by the Planning Department to address durability and aesthetics.

- For minor channels with depth less than 900 mm (3 ft), or for small, localized areas steeper than 5:1 on other channels, the City Engineer or County Public Works Director may allow the fence requirement to be waived.

7.4.7 Drainage Easements

- Drainage facilities must be located in a public street, road or lane, or within a public drainage easement. Necessary dedication for lines to be constructed on private property must be completed before the improvement will be approved for construction.

- Where a minor improvement of a drainage facility falls on adjacent property, written permission from the adjacent property owners for such construction and a copy of the approval of the adjacent owners shall be submitted to the City Engineer or County Public Work Director, prior to approval of the improvement plans. Agreements between property owners shall hold the City or County harmless from any damage claim arising from said agreement.

- Drainage easements shall be used for drainage purposes exclusively and shall not be combined with easements required for other public utility purposes unless it can be shown to the City Engineer or County Public Works Director that dual use of said easement will not be conflicting.

- For natural waterways, drainage easement or right of way (when required) shall be provided which includes the entire waterway area plus freeboard. In some locations the City or County may also require dedication of an access or maintenance road. Prior to final approval, the easement shall be staked by the developer or project proponent's engineer and reviewed by the City or County Public Works Director. In the case of a natural waterway having banks with side slopes steeper than two horizontal to one vertical, (2H:1V) the right of way may be required to be increased to provide width for not less that 2 to 1 slopes from the existing toe of bank, plus a 7.6-m (25-ft) wide buffer strip. Additional right of way will also be required where unstable ground conditions exist as determined by the City Engineer or County Public Works Director, based on detailed geotechnical, geomorphic and hydraulic studies completed by the project proponent or Developer. Procedures for completing detailed studies are outlined in Section 4.0.

7.4.8 Easements for Closed Conduits

Easements for closed conduits shall meet the following requirements:

- Minimum width of 3 m (10 ft) with pipe centered 0.75 m (2.5 ft) from the north or west edge. Whenever possible, rights of way for closed conduits shall be along or adjacent to property lines and outside of areas where structures are planned.

- On pipes of 600 mm (24 in) diameter and greater, or trenches exceeding 1.5 m (5 ft) in depth, the easement shall have additional width to provide ample working space as required by the City Engineer or County Public Works Director.

- Provide access and working space rights.

7.4.9 Property Rights for Open Channels

Property rights for major and intermediate open conduits shall have sufficient width to contain the open channel with side slopes, and at least one, 4.5-m (15-foot) wide service road.

The City Engineer or County Public Works Director may waive this requirement along constructed natural channels or open channels in parks and open space areas with good access.

SECTION 8.0

DESIGN OF DRAINAGE PUMPS

The Federal Highway Administration publication, *Highway Stormwater Pump Station Design – HEC 24* (FHWA, 2001) should be used as the technical reference. This is available at http://www.fhws.dot.gov/bridge/hydpub.htm.

- The use of drainage pumps shall be avoided whenever possible. They shall be used only with the approval of the City Engineer or County Public Works Director
- If the use of a drainage pump is approved, the drainage system shall be so designed as to provide for gravity outfall during summer months and periods of low water stages. If a low stage gravity outfall is impossible of impracticable, a pump of smaller capacity for low state flow may be used provided the City Engineer or County Public Works Director grants approval.
- Drainage pumps shall be equipped with standby equipment with alternating operation characteristics.
- When specified by the City Engineer or County Public Works Director, the outfall shall be equipped with floodgates of an approved design.
- Pumping installations shall be so designed as to accommodate a design storm as specified by the City Engineer or County Public Works Director.
- Pumping stations shall be designed so that gravity flow does not flow through the pump pit.
- Each pumping installation shall receive separate approval, including all machinery, electrical system, piping system, housing installation and other miscellaneous design features.

SECTION 9.0

STORMWATER MANAGEMENT FACILITIES

9.0 General

On-site stormwater management structures (either retention or detention) are **not** required for all developments in the San Luis Obispo Watershed by the City or County, except as noted in ***Section 3.3.*** However, the City or County will regulate the design and construction of stormwater storage facilities, including water quality and sediment detention basins (if proposed) to meet the requirements of this section and ***Section 3.7: Erosion Control***. This Section defines design requirements and describes appropriate analysis procedures and design criteria. The guidelines and design criteria have been established to simplify the design and subsequent maintenance of stormwater management facilities within the San Luis Obispo Creek Watershed. The FHWA Urban Drainage Design Manual HEC-22 (FHWA, 2001) provides guidance and procedures for hydrologic and hydraulic design. This is available at http://www.fhws.dot.gov/bridge/hydpub.htm. Any deviation from this set of guidelines will be subject to approval by the City or County Public Works Director.

Depending on the volumes of water stored and the height of the stored water, a stormwater management facility may be classified as a dam by the California Department of Water Resources Division of Safety of Dams (DSOD). DSOD regulated facilities generally include dams storing over 62,000 m^3 (50 ac-ft) of water, or are over 7.6 meters (25 ft) in height. Storage facilities subject to DSOD jurisdiction must be designed and constructed following DSOD guidelines. Structures not within DSOD jurisdiction, but greater than 1.8 m (6 ft) in height or with capacity greater than 19,000 m^3 (15 ac-ft) are to be designed and constructed in a manner that satisfies the DSOD criteria; except, the design event shall safely pass the 100-year event and the requirements for emptying are reduced to 72-hours.

Additional requirements for all storage facilities greater than 1.8 m (6 ft) in height or with capacity greater than 19,000 m^3 (15 ac-ft) are presented in this section. If the DSOD guidelines conflict in any case with requirements herein, the DSOD criteria should be used and the contradiction should be noted. Minor storage facilities those less than 1.8 m (6 ft) in height with a capacity less than 19,000 m^3 (15 ac-ft) will require a grading permit and erosion control plan, but no DSOD permit.

9.1 Types of Stormwater Management Facilities

Stormwater management facilities mitigate adverse impacts by holding stormwater and releasing it at a rate that will not cause damage downstream. There are several types of these facilities.

9.1.1 Detention Basin

Detention basins may be classified as:

Dry basins. The basins are designed to store water for only a short time during periods of high stormwater runoff. A drainage control structure, usually consisting of a pipe which controls the rate of outflow from the basin, is set in the bottom of the basin, thus providing for nearly complete emptying of the pond when inflow ceases. A sump may be provided below the invert to allow for sediment settling.

Wet basins. These basins are designed to maintain a permanent pool of water. The outlets are located above the permanent water surface, so the basin does not drain completely. Wet basins may be used for water quality improvement and also to provide wildlife enhancement. Because of higher, long-term maintenance requirements necessary to preserve that proper functioning, these facilities are allowed only with specific approval of the City or County.

9.1.2 Retention Basins

A retention structure stores all or a portion of the inflow for a prolonged time period. These resemble detention basins; yet have no outlet (other than emergency outlets). Outflow is via infiltration or evaporation. In general, the design requirements for a retention structure are consistent with those for a detention structure, unless noted otherwise herein.

Because of the general lack of permeable soils in the San Luis Obispo watershed, retention basins are allowed only with specific approval of the City or County. Also, as with a wet detention basin, a retention basin requires long-term maintenance to insure proper performance. Therefore, any proposal for a retention basin will require submittal of an acceptable long-term maintenance plan.

9.1.3 Special Facilities

Parking lots or athletic fields may be used to provide additional storage of stormwater runoff from less-frequent, higher-intensity storms when used in conjunction with another storage facility. Parking-lot storage may be used for storms greater than the 10-year design storm, provided that the following conditions are met:

- The depth of water detained does not exceed one foot at any location in the parking lot area for the 100-year design storm; and
- The minimum gradient of the parking lot area subject to ponding is 1%; and
- The emergency overflow path meets the requirements for pond systems; and
- Ponding is restricted to areas that will cause the least inconvenience to parking area users.

Detention for the 10-year design storm may be permitted with specific approval of the City Engineer or County Public Works Director. The design criteria for a 10-year storm would be the same as the requirements of a 100-year storm, as noted above, with the exception of the depth of water stored. The depth of water detained cannot exceed .150 mm (0.5 ft) at any location in the parking lot under the 10-year design storm.

9.1.4 Regional Facilities vs. On-Site Detention

If storage facilities are planned for an individual site, rather than as a component of an overall regional plan, the storage is referred to as *On-site* Detention Facility. Such on-site facilities are designed to control short, intense storms that produce the greatest peak flows. The facilities typically are small in scale and can be used when regional detention is not available or if on-site storage is necessary to reduce peak discharge for downstream pipes, culverts, ditches, or streams.

Facilities designed as a component of a Master Drainage Plan are classified as a ***Regional Detention Facility***. Generally, a Drainage Master Plan that incorporates such regional storage facilities can produce more economical and effective mitigation of increase runoff than is possible with numerous small detention basins. Regional facilities typically are larger than on-site, privately owned basins, and are designed to control systematically runoff from the total watershed. Detention facilities identified within these regional drainage studies must meet all applicable drainage performance requirements. Any variation from these standards requires prior approval from the City or County.

Coordinated Regional Detention Facilities that take into account the entire watershed area are preferred over individual stormwater facilities. When a regional drainage study has been conducted and regional basins are designed, the regional facility will always take precedence over local basin design. When necessary, on-site detention can be provided on a temporary basis until a Regional Detention Facility is built, and removed subsequent to completion of the Regional Detention Facility.

9.1.5 Location

When choosing a location for a basin, the following factors should be taken into consideration:

- Topography: Check for obvious low and high points in the area. The greater the excavation, the higher the costs. Also, look for natural neckings of the watershed if a dam is necessary.
- Location in the Watershed: Locate the basin far enough down in the reaches of the watershed to most effectively reduce the peak flow by intercepting the greatest number of tributaries to the main drainage channel. However, a basin located too low in the watershed may require upstream channel improvements. The timing of outflow hydrographs should be examined closely for basins low in the watershed.
- A basin located too high in the watershed allows all downstream lands to drain uncontrolled, which will increase the total flow to an undesirable level. This may

result in additional downstream channel improvements or additional downstream basins.

- Elevation: Consider the difference in elevation between the inlet and outlet to obtain the optimum amount of volume for the minimum of area. Also, consider the best outflow and inflow characteristics possible (i.e., a free outflow and inflow).
- Property Costs: Consider the cost of prospective property for the basin. Lower property costs, help to lower basin costs.
- Outlets: Outlet pipes should not flow at greater than 3 meters (10 feet) per second at the outlet, without an energy dissipater or adequate creek protection downstream.
- Groundwater Table: Determine the elevation of the groundwater table. If possible, avoid any location where the groundwater table is higher than the bottom elevation of the basin. Groundwater flow can have a significant effect on the construction and operation of a detention basin.
- Visibility: For safety and ease of policing, the basin should be situated so that it is visible by police patrols. Whenever possible, a road should be located along at least one side of the basin.

9.2 Hydrologic and Hydraulic Analysis for Detention/Retention Basin Design

Inflow hydrographs for design and analysis of impoundments must be computed with procedures described in ***Section 4.0*** of this manual. A routed hydrograph method or watershed wide hydrology model shall be used for design. Alternate methods will require the approval of the City or County Public Works Director.

The engineer is cautioned here that, even though this Drainage Design Manual stipulates the event for which a structure is to be designed (**Section 9.4.1**), performance of the structure with larger and smaller events must also be evaluated. For example, suppose a structure is designed to reduce the post-development peak due to a 100-year, 24-hour event. As a component of the complete analysis, the engineer should determine also downstream flows due to, for example, the 10-year, 24-hour event. The 10-year post-development peak will almost certainly be greater than the 10-year pre-development peak. However, without proper consideration in design of the detention outlet, the structure might not reduce this 10-year post-development peak. Thus, downstream flooding due to this smaller-than-design event will be greater, even though detention is provided. Further, in some cases the detention may delay a flood peak so it coincides in time with peak from another subcatchment downstream. In that case, the detention may actually increase downstream flooding for the design event. The engineer must provide the details of careful, systematic analysis to identify and remedy these potential problems.

9.2.1 Provisions For Sedimentation

The design volume of the basin must be sized to include the capacity for a five (5) year accumulation of sediment. Generally, the basin should be cleared out when it is half-full, as determined on a marked staff in the bottom of the basin, or a mark on a riser pipe. The amount of potential sedimentation in the basin shall be determined by a soils engineer or hydrologist, using the procedures such as those outlined in the *Association of Bay Area Government's* (ABAG) Manual of Standards for Erosion and Sediment Control (May 1995) or as approved by the City Engineer or County Public Works Director.

9.3 Geotechnical Requirements

Any detention basin design must be accompanied by a soils report. This report should address allowable safe basin slopes with respect to liquefaction, rapid draw down, wave action and so forth. Additionally, the report should also address sedimentation transport from areas above the basin and allowable bearing pressures where structures are to be placed. The soils report must address the level of the water table and the effects of the basin excavation on the water table.

9.4 Basin Size Criteria

Basin size varies with the amount of inflow, allowable outflow, existing soil conditions, freeboard requirements and secondary uses. These variables are further discussed below.

9.4.1 Inflow

Inflow is a function of the size and shape of the watershed above the basin, its existing and projected future land use and the design storm frequency and duration.

The relationship between size of watershed and design storm frequency is as follows:

- Watershed size 0 to 2.6 km^2 (0 to 1 mi^2) - 10-year frequency with 300 mm (1 ft) freeboard
- Watershed size 2.6 km^2 to 10 km^2 (1 to 4 mi^2) - 25-year frequency with 300 mm (1 ft) freeboard
- Watershed size 10 km^2 or more (4 or more mi^2) - 100-year frequency, with 600 mm (2 ft) freeboard.

The duration of a storm needs to be considered to determine inflow. Generally, the high intensity-short duration storms tend to determine basin size. However, basin performance must also be checked for the low intensity - long duration storms. These latter storms generate a higher flow volume (over a longer time) and, depending on the outflow provisions for a specific basin, may therefore influence basin size by the need for rapid basin drawdown or dewatering.

9.4.2 Allowable Outflow

The allowable outflow from a basin is determined by the size of the existing drainage facilities downstream. If the environmental impacts and proportional social costs for expanding these facilities are high, a large basin may be required to reduce outflows to acceptable levels downstream.

The amount of outflow can be regulated with a variable opening gate or a fixed outfall structure. The City or County prefers the latter. Such a structure must include an outfall pipe of a size and length that will give positive control on the outfall head. A typical fixed outfall structure consists of a principal spillway or a series of pipes of graduated size, and an emergency spillway. The principal outlet regulates the design discharge from the watershed above at a water level in the basin that does not exceed a certain maximum elevation. The emergency spillway is used to relieve the basin of extra runoff, which could threaten the integrity of the basin. In some cases, it is used in conjunction with the primary spillway. If flow through the emergency spillway is occurring, the combined flow of both the primary and emergency spillways must not exceed the capacity of downstream pipes and waterways.

The interaction between basin size, inflow and outflow can be modeled using the San Luis Obispo SLO/Zone 9 HEC-HMS hydrology model.

9.4.3 Freeboard Requirements

Regardless of the size of the watershed upstream of a basin, the 100-year storm must be routed through the basin and the basin sized so that the maximum water surface elevation (due to a 100-year storm) is 600 mm (2 ft) below the lowest point along the top of the basin. At a minimum the basin must contain the 10-year flow without release to emergency spillway. If flows over the emergency spillway do occur, provisions must be made or be in place that will convey such flows safely.

9.4.4 Basin Dewater Provisions

The basin and its outfall must be sized so that approximately 85% of the total stormwater storage, excluding sediment storage in the basin can be recovered within twenty-four hours of the peak inflow.

9.4.5 Secondary Uses

Basin size also varies if secondary use is desired. If the basin is to double as a passive, nature-viewing and permanent pond area, the depth of the permanent pond should not be counted as a flow storage area. Also, if the basin is to be used as an active play field, the basin bottom or a portion of it, should be raised to avoid constant inundation. Additionally, the basin side slopes should be flattened to allow turfing and mowing and use by the public.

9.5 Basin Design

Detention and retention basins constructed as a component of a stormwater management system must satisfy the following requirements. Exceptions to these requirements may be granted by the City or County Public Works Director.

- The basin must be designed to aesthetically harmonize with its surroundings.
- The length-to-width ratio of the basin must be at least 2:1; a ratio of 5:1 is preferred. The basin inlet and outlet must be located as far apart as possible.
- Interior earthen side slopes shall be no steeper than 3H:1V; exterior side slopes shall be no steeper than 2.5 H:IV. Steeper slopes shall be confirmed by a qualified geotechnical engineer and approved by the City or County.
- Basin walls may be retaining walls, provided that the design is prepared and certified by a qualified engineer. A fence must be placed along the top of the wall.
- The basin flow must slope towards the low-flow channel with a minimum slope of 1%, measured perpendicular to the low-flow channel. The slopes must be designed as close to the minimum as possible to facilitate sedimentation. Because sediment tends to accumulate around the lowest outlet, the invert elevation of any outlet shall be located 150 mm (0.5 ft) above the basin floor to minimize clogging. Care must be taken to eliminate accumulation of stagnant water within the pond.
- All finished earthen slopes must be re-vegetated as soon as possible.
- Maintenance of all storage facilities must be addressed in the design and construction pursuant to ***Section 3.10***. For basins greater than 5,000 m^3 (4 ac-ft) storage; vehicular access for maintenance of the pond and outlet works, removal of sediment, and removal of floating objects during all weather conditions must be provided. An access road must be provided to the basin floor of all detention faculties. This road must have a minimum width of 3.7 m (12 ft) and a maximum grade of 20%. Turn-arounds at the control structure and the bottom of the basin must have a 12-m (40-ft) minimum outside turning radius. A maintenance plan must be developed and provided along with the design documents.
- Any storm water concentrated due to the grading of the access strip(s) shall be conveyed to a point of adequate discharge in a manner acceptable to the City or County. The facilities handling the concentrated storm water shall be considered as storm drains and shall be so designed. An outlet structure is required if the pipe discharges into a channel or the detention basin. Erosion protection shall be installed at the lower terminus of the pipe.
- If a basin is to double as a park during the dry months, it must have at least three (3) public points of access.

9.6 Spill Way Design

Regional, or larger on-site facilities can pose significant hazards to public safety in the event of failure. In addition to the outlet control structure, an emergency overflow spillway (secondary overflow) must be provided. This spillway must satisfy the following requirements:

- The spillway must be designed to pass the 100-year design storm event if the outlet works fail or if a runoff event exceeds the design event. The spillway design will be based on peak runoff rates for developed site conditions, assuming that the basins fill to the crest of the spillway prior to the beginning of the design event.
- The spillway must be located so overflow is conveyed safely to the downstream channel.
- The spillway must be protected against erosion and scour, typically with rock or concrete lining.

9.7 Outlet Works Design Requirements

9.7.1 Outlet Types

Outlets are designed for planned release of water from a detention structure. The outlets may consist of separate conduits of various sizes, or of several inlets to a chamber or manifold that leads to a single outlet pipe or conduit. The lower outlet functions regardless of the volume of inflow. The capacity of other outlets is determined with appropriate weir, orifice, or pipe formula, depending on the design of the outlet.

9.7.2 Outlet Standards

Outlet works constructed as a component of a stormwater storage system must satisfy the following requirements. The City and/or County, for good reason, may grant exceptions to these requirements.

- A pond overflow system must provide controlled discharge (emergency spillway) for the 100-year design event without overtopping the pond embankment and maintain adequate freeboard. The design must provide controlled discharge directly into the downstream conveyance system or safe drainage way. The principal outlet must be able to drain the detention facility within 48 hours of the end of the 100-yr storm by gravity flow through the principal outlet.

- Reinforced concrete pipe should be used for the principal outlet for a detention basin. The minimum acceptable outlet pipe diameter is 300 mm (12 in). If a riser is used, provision must be made to completely drain the pond. In general, the riser pipe diameter must be at least one standard pipe size, or a minimum 150 mm (6 in) greater than the barrel pipe diameter. The minimum acceptable riser pipe diameter is 600 mm (24 in). A corrugated metal pipe may be used for the outlet, if approved by the City Engineer or County Public Works Director.

- The formation of vortices can causes significant head loss and reduce the discharge for a given head. Consequently, the potential for vortex formation must be evaluated during design, and anti-vortex devices must be installed if the basin length to width ratio (with length measured along the direction of flow entering the basin) is less than 2, if the basin outlet is not centered with respect to basin width, or if, in the judgment of the City Engineer or County Public Works Director, the basin shape is irregular enough to cause the formation of eddies during high flow events.

- Depending on the geometry of the outlet structure (either drop-inlet riser or hood-inlet pipe), discharge for various depths can be controlled by the inlet crest (weir control), or the riser or barrel opening (orifice control), or the riser or barrel pipe (pipe control). Each of these flow controls shall be evaluated when determining the rating curve of the principal outlet.

- Flow-control facilities must be designed for unrestricted flow downstream of the outlet works. Additional storage capacity must be provided if the release rate capability is reduced due to backwater conditions. In other words, the flow control facilities must be selected on the basis of the actual flow. This guarantees the allowable release rate if downstream restrictions are removed and the backwater condition is eliminated.

- Conduits designed for prolonged pressure flow must be provided with seepage-drainage diaphragms or geotextiles to control erosion of fine material. If the outlets discharge onto easily eroded materials, stilling basins or other energy-dissipating devices shall be provided.

- Outlets must not depend on human intervention to operate gates or other controls during a storm event.

- The number of conduits through the embankment should be minimized, and care should be taken to ensure against leaky conduit joints in the embankment.

- Thin-walled conduit should not be used in the embankment without a protective exterior encasement.

- The basin and outlet works should be designed for debris build-up, accounting for the resulting energy loss.

9.7.3 Trash Racks

Outlets for detention ponds must be protected by trash racks. These are grates, grills, filters, or screens that protect the outlet from plugging with debris. The following provides guidance for design of racks for detention facilities:

- Trash racks must be large enough that partial plugging will not restrict outflow. As a rule-of-thumb, the trash rack area should be at least ten times larger than the outlet orifice. For very small outlets, an even larger ratio may be necessary to control the initial flush of debris.

  The rack should be sufficiently far from the outlet opening to avoid interference with the hydraulic performance of the outlet.
- Rack openings should be appropriate for the dimensions of the outlet protected: a smaller outlet demands smaller openings. Multiple racks with varied spacing may be used if the outlet consists of multiple openings of various sizes.
- Trash racks must have hinged opening to permit access for removal of accumulated debris and sediment.
- Maintenance access must be provided, as well as a means to drain the pond if the basin is a wet basin.

9.7.4 Outlet Safety

Outlet works create a potential hazard when operating. Fencing and trash rack must be provided on both upstream and downstream openings, and public access must be limited. Outlets shall be planned and designed to minimize flow velocities.

9.8 Maintenance Requirements

9.8.1 Access

The basin design must demonstrate that access for maintenance can be accomplished. (See Basin Design ***Section 9.5***).

9.9 Fencing

Safety features to protect the public must be incorporated. Fencing, consisting of a 1.8-m (6-ft) vinyl-coated chain-link meeting Caltrans standards, should be provided around the perimeter of detention basins when appropriate. Access gates constructed of the same material, as the fencing must be included with a minimum opening of 3.7-m (14-ft).

If the gate is located at a road, it shall be set back far enough to allow maintenance vehicles to park off the road while the gate is being opened. The gate at the publicly maintained road shall have side panels or other devices to prevent vehicles from driving around the gate. The gates shall be equipped with a locking feature acceptable to the City/County. The City or County will furnish the necessary lock(s).

Detention basin perimeter fencing in rural areas may consist of 1.8 m (6 ft), non-climb field fencing (opening 51 mm vertical, 102 mm horizontal) (2 inch V: 4 inch H) at the bottom and three (3) strands of smooth wire above. Backyard fencing shall be 1.8-m (6-in) chain link. All headwalls and other vertical drop-offs higher than 900 mm (3-ft) should be fenced with 1.1-m (3.5 ft) chain-link fence as specified above. Slope fencing must be approved by the city or County and will be justified only in highly visible locations. A 0.9-m (3-ft) flat area adjacent to such slope fencing will be required.

9.10 Landscaping

The City or County may require a detention basin to blend in with its natural surroundings. As a minimum, basin side slopes and bottom shall be seeded to result in a full grass cover (see **Section 10.3** for grass seed mix). Basin side slopes shall be planted with groups of bushes and/or trees of a spacing and species approximating existing vegetation on property adjacent to the basin. It is recommended that existing top soil be saved before basin excavation is begun. This topsoil should be spread on the basin and side slopes and worked in to provide suitable environment for landscaping.

9.11 Joint Use

If there is a secondary use for the basin (other than flood control) the entity proposing secondary use will have to enter into a joint use agreement with the City or County in which the terms for liability, policing, maintenance, etc., are set forth. If basin is to double as a public park, extra landscaping needs to be provided to screen private residences around its perimeter.

9.12 Submittal Requirements

The City or County will review all proposed detention basin designs. In order to facilitate review, the design submitted should contain the following retention:

Calculation and Graph

- Watershed Parameters
- Inflow Hydrograph
- Stage vs. Storage Curve
- Stage vs. Discharge Curve
- Basin Routing (Inflow-outflow hydrographs for various frequencies and durations)
- Summary Table of All Basin Routings

Map and Drawing

- Hydrology Map Showing Contours, Basin Location and Watershed Boundaries
- Basin Drawings

Drawings should show plan and vertical views with dimensions of all structures, including the emergency spillway detail.

SECTION 10.0

EROSION CONTROL AND STORMWATER QUALITY MANAGEMENT

10.1 General

This Section identifies standards for erosion prevention, sediment control and stormwater quality management. The provisions of this section are intended to prevent and reduce adverse impacts to the drainage system and water resources of the SLO Creek Watershed, pursuant to ***Section 3.7***. In combination with other state, federal, and local laws and ordinances, these requirements are intended to protect the beneficial uses of waters within the watershed. ***Section 10*** specifies the use of erosion prevention techniques, sediment control measures, and other stormwater Best Management Practices.

- Erosion prevention techniques are designed to protect soil particles from the force of rain and wind so that they will not erode. These techniques include, but are not limited to such things as construction scheduling, ground cover and plantings, and installation of erosion control matting.

- Sediment control measures are designed to capture soil particles after they have been dislodged and attempt to retain the soil particles on-site. These measures include, but are not limited to silt fences, sediment barriers, and settling basins. Both erosion prevention techniques and sediment control measures have appropriate uses; however, it has been shown that sediment control measures are less effective in preventing soil movement and water quality impacts than erosion prevention techniques.

10.1.1 Authorized Personnel

Persons authorized to prepare erosion control plans include the following:

- A Certified Professional Soil Erosion and Sediment Control Specialist.
- A California Registered Civil Engineer.
- A California Licensed Landscape Architect
- A California Registered Geologist, certified as an Engineering Geologist
- A California Licensed Surveyor may also determine slope but not prepare an Erosion Control Plan

Section 3.7 permits use of ***Standard Erosion Control Measures*** (instead of submittal of a ***Detailed Erosion Control Plan***) for any grading or land clearing for a building project (includes driveways up to 50 feet in length, but not road construction) or on slopes less than 10%, and where the project areas is less than one hectare (2.5 acres). For project areas greater than one hectare, on slopes greater than or equal to 10% or in sensitive areas, a full, ***Detailed Erosion***

Control Plan is required for road construction projects and building projects. The Standard Erosion Control Measures shall appear either attached to the grading plan (if one is required to be submitted), or on a plot plan (if no grading plan is required), as part of the Building Permit application.

10.1.2 Slope Determination

Before Standard Erosion Control Measures can be applied to a project, it must be determined that the slope is not more than 10%. This is calculated according to the following procedures:

Percent slope of the building development area is measured perpendicular to the contours across the building pad and driveway when the driveway is less than 15 m (50 ft) in length. The slope determination will be made by evaluating a plot plan having contour intervals of 0.25 m to 1.5 m (or 1 ft to 5 ft if mapped in English units), with a minimum scale of 1 to 500 (of 1" equals 40 feet) if mapped in English units).

10.2 Erosion Control and Stormwater Management Manuals

The ***Association of Bay Area Governments (ABAG) Manual of Standards for Erosion and Sediment Control (Second Edition, May 1995)*** is adopted as the erosion control standards manual for planning and design in the SLO Creek Watershed. Drawings and design details from this source may be used in submittal of Standard Erosion Control Measures and detailed Erosion Control Plans.

The ***Erosion and Sediment Control Field Manual*** available from the California Regional Water Quality Control Board, San Francisco Bay Region is adopted as the field manual for use by contractors and City and County inspectors in the field review of projects.

The ***California Stormwater Best Management Practices Handbooks*** available from the Stormwater Quality Task Force, March 1993, are adopted for use in preparing Stormwater Pollution Prevention Plans (SWPPP). Separate handbooks are available for: 1) Construction Activity; 2) Industrial/Commercial; and, 3) Municipal work areas.

10.3 Standard Erosion and Sediment Control Measures

The following standard measures for soil erosion and sediment control are to be used on small building construction projects less than 1.0 hectare, (2.5 acres), (except for road construction projects), with natural cross slopes of 15 percent or less, and not located in critical areas as defined in ***Section 3.6***.

The techniques and methods contained and prescribed in the latest addition of the Association of Bay Area Governments Standards for Erosion and Sediment Control Plans, should be used along with the following additional guidance and requirements:

10.3.1 Gravel Construction Entrance

- A gravel construction entrance is required (***Figure 10-1***). If there is more than one vehicle access point, a gravel construction entrance shall be required at each entrance. The responsibility for design and performance of the driveway remains with the permittee.

- Vehicles or equipment shall not enter a property adjacent to a stream, watercourse, or storm and surface water facility, or wetlands unless adequate measures are installed to prevent physical erosion into the water or wetland.

10.3.2 Catch Basin Protection

- A filter system shall be used (Figure 10-2) on catch basins (drop inlets) in public streets as a means of sediment control. The installation shall conform to the standard details in the cited references.

10.3.3 Sediment Filters/Barriers

- For projects constructed during the period of October 15 through April 15, a silt fence or straw wattle dike shall be installed along the downslope edge of the disturbed area, prior to the commencement of grading. The sediment retention structure will be located so that all runoff from the construction site is contained. Sediment retention structures are to be inspected regularly and sediment removed when the depth of sediment is one half the height of the structure. Silt fences and straw wattles shall be installed according to the standard references cited.

- Straw wattles (Figure 10-3) can be used as dikes to stabilize temporary channel flowlines or as a perimeter filter barrier. Straw wattles must be installed in a trench, staked and backfilled if they are to be effective in reducing flow velocity and filtering sediment from runoff. Straw wattles can also be placed around stormdrain drop inlets and at back of curb to trap sediment.

- Straw wattles should not remain in place more than 12 months after installation unless it can be determining significant deterioration has not occurred. When used as a perimeter filter, sediment should be removed when material is within 76 mm (3 in) of the top of any wattle.

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2. Note: The Standard Erosion Control Drawings were provided by and used with the permission by Salix Applied Earthcare, a Natural Resource Consulting firm in Redding, California. The drawings are available in CAD format in "Erosion Draw". Neither the City of County of San Luis Obispo specifically requires use of, or endorses Erosion Draw, and authors of Erosion Control Plans may use other, similar drawings and platforms that achieve the same results.

- Filter fences (also known as silt fences - see Figure 10-4) should be installed where sediment from sheet flow or rill and gully erosion will enter directly onto adjacent property. When installing, it is important the fabric material be anchored into a trench and backfilled.

- Maintenance of filter fences is similar to that of straw bale dikes in that the fabric must be inspected and needed repairs implemented after every storm event. Sediment deposits should be removed when material reaches no more than a depth of one-half the fence height.

10.3.4 Plastic Sheeting

- Plastic sheeting shall generally not be used as an erosion control measure over large areas.

- Plastic sheeting may be used to protect small, highly erodible areas, or temporary stockpiles of material. If plastic sheeting is used, the path of concentrated flow from the plastic must be protected.

10.3.5 Existing Vegetation and Revegetation

As far as is practicable, existing vegetation shall be protected and left in place, in accordance with the clearing limits on the approved Grading and Erosion Control Plans. Work areas shall be carefully located and marked to reduce potential damage. Where existing vegetation has been removed, or the original land contours disturbed, the site shall be revegetated, and the vegetation established, as soon as practicable, but no later than **October 15th.**

10.3.6 Wet Weather Measures

On sites where vegetation and ground cover have been removed from **more than 0.4 ha (1 ac)** of land, vegetative ground cover shall be planted on or before **September 15** with the ground cover established by **October 15**. As an alternative, if a protective ground cover is not established by **October 15**, the open areas shall be protected through the winter with straw mulch, erosion blankets, or other method(s) approved by the City or County.

10.3.7 Seeding

Seeding shall be as follows, or as recommended by a California Licensed Landscape Architect or a Certified Professional soil Erosion and Sediment Control Specialist, or a City or County approved biologist.

SEED MIX ONE (Application rate = 40 kg/ha or 35 lb/ac)		**SEED MIX TWO** (Application rate=40 kg/ha or 35 lbs/acre)	
Blando brome	40%	Blando brome	35%
Zorro annual fescue	8%	Rose clover	20%
Lana vetch	12%	Annual ryegrass	15%
Rose clover	15%	Crimson clover	10%
Crimson clover	15%	Creeping red fescue	5%
Sub clover	10%	Zorro annual fescue	5%
TOTAL	**100%**	**TOTAL**	**100%**

FERTILIZER

(where necessary, as determined by soil tests)
12-12-12 450 kg/ha (400 lb/ac), or
15-15-15 340 kg/ha (300 lb/ac), or
16-20-0 340 kg/ha (300 lb/ac).

MULCH

Straw 3,400 kg/ha (3,000 lb/ac), or
Wood fiber (if hydroseeded) 2,300 kg/ha (2,000 lb/ac)

10.3.8 Temporary Erosion Protection Measure Removal

- The temporary erosion prevention and sediment control measures shall remain in place and be maintained in good condition until all disturbed soil areas are permanently stabilized by installation and establishment of landscaping, grass, mulching, or otherwise covered and protected from erosion by permanent materials.

10.3.9 Submittal Requirements

The submittal for use of **Standard Erosion Control Measures** can be brief and shall include a plot plan or grading plan identify the following:

- Site location; assessor parcel number and address (if known)
- Property owners name, address and phone number, including emergency number
- Building contractors name, address and phone number.
-
- General locations where measures will be installed.
- Installation details shall be attached to the plot plan (these can be copied from the Standard references)
- A signed statement agreeing to use and maintenance of Standard Erosion Control Measures.

10.3.10 Review and Field Checks

- Upon submittal of the grading or plot plan with Standard Erosion Control Measures, it is reviewed to make sure that all information requested is on the plans. If the project is to be completed less than 2 months before the rainy season (August 15) the measures must be shown on the plans to avoid any problems in the future if the schedule should stop for some unforeseen circumstance.

- Plans are reviewed to determine if the project is located in a geologically sensitive and unstable area or along a stream course. If the project is located in such area, then a full Erosion Control Plan is required.

- The site may be field checked to verify that there are no observable sensitive areas on the site and the standard measures proposed are adequate. If found inadequate, a full Erosion Control Plan may be required.

- Depending upon the timing of the project, there will be one to four field inspections. If the project is completed over the summer (by August 15) and includes landscaping, the regular final building inspection will include the Standard Erosion Control Measures inspection. If project is not completed by the onset of the rainy season, then the first inspection will be between September 15 and October 1. All temporary erosion and sediment control measures are to be installed by October 15. Other field inspections will be made to assure that revegetation has occurred and is growing (sometime in November through March.).

10.4 Detailed Erosion Control Plan Requirements

An Erosion Control Plan submittal will be required for sites larger than 1 hectare (2.5 acres) or for buildings on slopes equal to or over 10%, or projects located within sensitive areas, as outlined in ***Section 3.6.*** The ***Detailed Erosion Control Plan*** submittal must comply with all of the requirements for the Standard Erosion Control Measures and also include a written narrative and detailed site plan.

10.4.1 Narrative

Written narrative (to be included with Plan) on letterhead or signed plan sheet of person responsible for Plan preparation.

- Proposed schedule of grading activities and infrastructure milestones in a chronological format. For example, easterly slope rough grading complete, streets graded, storm sewers and inlets installed, paving complete on Street X, creek outfall structure complete, etc.
- Potentially affected areas adjacent to site

- Description of soils, geology, vegetation and nearby streams
- Critical areas of high erodibility potential; unstable slopes
- Dates for beginning of phased grading areas and dates that areas will be stabilized
- Description of erosion control measures on slopes, lots, streets, etc.
- Sediment detention basins, including design assumption and calculations
- Description of Emergency Erosion and Sediment Control Plan for approaching storms within 48 hours.
- Name and 24 hour telephone number of person responsible for erosion and sediment control
- A signed acknowledgment of developer and general contractor that they are familiar with and agree to implement abide by the plan, including routine inspection and maintenance, SWPPP documentation and emergency erosion control measures.

10.4.2 Site Plan

The site plan shall include the following information:

- Scale, north arrow, legend
- Vicinity map
- Watershed boundaries within project
- Contours and spot elevations indicating runoff patterns before and after grading
- Critical areas within or near the project (streams, lakes, wetlands, landslides, steep slopes, etc.)
- Limits of clearing and grading
- Creek setbacks top of bank and existing vegetation and any special trees/wetlands to be fenced and protected
- Location and types of temporary and permanent erosion and sediment control measures
- Site access locations
- Signature block for preparer of plan
- Additional plans that may be needed to illustrate narrative addressing stages of construction such as street graded-no storm drains; storm system installed; streets paved; etc.

10.4.3 General Erosion and Sediment Control Notes to be Included on Site Plan for Detailed Erosion Control Plan

- Contractor/Owner: name, address, phone number. It shall be the owner's responsibility to maintain control of the entire construction operations and to keep the entire site in compliance with the soil erosion control plan.

- Civil Engineer or ECP preparer: name, address, phone number

- Construction Superintendent: name, address, 24-hour phone number

- Contractor: name, address, 24-hour phone number

- This plan is intended to be used for interim erosion and sediment control only and is not to be used for final elevations or permanent improvements.

- Owner/contractor shall be responsible for monitoring erosion and sediment control measures prior, during, and after storm events. Monitoring includes maintaining a file documenting on-site inspections, problems encountered, corrective actions, and notes and a red-line map of remedial implementation measures.

- Reasonable care shall be taken when hauling any earth, sand, gravel, stone, debris or any hazardous substance over any public street, alley or other public place. Should any blow, spill, or track over and upon said public or adjacent private property, immediate clean-up shall occur.

- Construction entrances shall be installed prior to commencement of grading. All construction traffic entering onto the paved roads must cross the stabilized construction entranceway.

- Sanitary facilities shall be maintained on-site.

- During the rainy season, all paved areas shall be kept clear of earth material and debris. All earth stockpiles over 0.75 m3 (1.0 yd3) shall be covered by a tarp and ringed with straw bales or silt fencing. The site shall be maintained so as to minimize sediment-laden runoff to any storm drainage system including existing drainage swales and watercourses.

- Construction operations shall be carried out in such a manner that erosion and water pollution will be minimized. State and local laws concerning pollution abatement shall be complied with, including dust control.

- Contractor shall provide dust control as require by the City or County Standard Specifications.

- The facilities shown on this plan are designed to control erosion and sediment during the rainy season, October 15 to April 15. Facilities are to be operable prior to October 1 of any year. Grading operations during the rainy season, which leave denuded slopes, shall be protected with erosion control measures immediately following grading on the slopes. This will include use of straw mulch and tackifier, and erosion control blankets.

- This plan covers only the first winter following grading with assumed site conditions as shown on the Detailed Erosion Control Plan. Prior to September 15, the completion of site improvement shall be evaluated and revisions made to this plan as necessary with the approval of the City Engineer or County Public Works Director. Plans are to be resubmitted for approval prior to September 1 of each subsequent year until the City or County accepts site improvements.

10.5 Procedures for Review and Inspection of Detailed Erosion Control Plans

Submission of a full **Detailed Erosion Control Plan** must accompany any grading or building permit application, as noted in ***Section 3.7*** of the **Core Requirements**. The City or County Public Works/Engineering Departments will review the packet submitted for completeness, and undertake a preliminary review for compliance with the requirements outlined in this section. If the City and /or County Public Works / Engineering Departments recommends approval of the plan, it will be returned to the City Community Development Department or the County Planning Department for further processing of any related permits, such as a grading plan permit.

On the ground compliance inspection will be coordinated among the City or County Engineering, Planning, and Building Inspection. Following plan approval the City or County will: (1) make an pre-winter inspection **(by October 1)** to verify that all temporary Erosion Control Measures have been installed according to the approved plan,(2) make at least one interim inspection during the winter rainy period to insure adequate on-going maintenance and repair of the erosion control measures, and (3) make a final inspection at project construction completion to verify that all required permanent erosion control measures, including any planting and revegetation elements have been installed according to this plan. On-site building contractor documentation of all on-going Erosion Control Plan site inspection (SWPP before and after inspection/repair documentation), maintenance and repair both before and following significant rainfall events will also be checked during these visits.

10.5.1 Maintenance

The permittee shall maintain the facilities and techniques contained in the approved ***Detailed Erosion Control Plan*** so as to continue to be effective during the construction phase, post construction phase, establishment of permanent vegetation, or any other permitted activity. If the facilities and techniques approved in an Detailed Erosion Control Plan are not effective or sufficient as determined by a City or County site inspection, the permittee shall submit a revised plan within three working days of written notification by the City or County. Upon approval of the revised plan by the City or County, the permittee shall immediately implement the additional facilities and techniques included in the revised plan. In cases where erosion is likely to occur, the City or County may require that the applicant install interim control measures prior to submittal of the revised Erosion Control Plan.

10.5.2 Inspection

Initial Inspection

On a site development or any other type of project, the erosion prevention and sediment control measures shall be installed prior to **October 1**. The permittee shall call the City or County prior to the foundation inspection of a building for an inspection of the erosion prevention and sediment control measures for that property.

Owner Inspections and Inspection Logs

The owner shall be required to inspect erosion prevention and sediment control measures and provide information on log forms provided by the City or County. Inspections shall be completed as required by the Erosion Control Technical Manual or the Detailed Erosion Control Plan. Logs and a red-lined, mark-up of the Erosion Control Plan drawing are to be maintained on-site and made available to City or County inspectors upon request.

Final Inspection

A final erosion control inspection shall be required prior to the sale or conveyance to new property owner(s) or prior to the removal of temporary erosion prevention and sediment control measurements, and to verify that all proposed permanent measures have been correctly installed.

10.6 Procedures for the Control of Runoff into Storm Drains and Watercourses

This section presents procedures and implementation specifications that the City and County will require construction contractors and builders, and individual homeowners to implement for the control of runoff into storm drains and watercourses from construction and building sites in the SLO creek watershed. These are in addition to the erosion control measures presented in the previous section. Implementation and on-going construction site maintenance and management of stormwater control measures using these procedures will be required for all projects for which the City or County Public Works/Engineering, or Community Development (Planning/Building) Departments issue permits.

The procedures are based on construction site Best Management Practices (BMPs) that were developed by the California Department of Transportation (Caltrans) as modified by the City of Santa Barbara. The full Caltrans BMPs can be obtained by logging onto the Caltrans web site at *http:/www.dot.ca.gov/hq/construc/stormwater.html*. Standard Specifications where referenced in this section means the most current edition of Caltrans Standard Specifications.

The following control measures are contained in this section:

- **BMP 1** Street Sweeping and Vacuuming
- **BMP 2** Water Conservation Practices
- **BMP 3** Dewatering Operations
- **BMP 4** Paving and Grinding Operations
- **BMP 5** Illicit Connection/Illegal Discharge Detection and Reporting
- **BMP 6** Potable Water/Irrigation
- **BMP 7** Vehicle Equipment Cleaning
- **BMP 8** Vehicle and Equipment Fueling
- **BMP 9** Vehicle and Equipment Maintenance
- **BMP 10** Stockpile Management
- **BMP 11** Spill Prevention and Control
- **BMP 12** Solid Waste Management
- **BMP 13** Concrete Waste Management
- **BMP 14** Sanitary/Septic Waste Management
- **BMP 15** Liquid Waste Management

BMP 1 Street Sweeping and Vacuuming

I. Definition and Purpose

Practices to remove tracked sediment to prevent the sediment from entering a storm drain or watercourse.

II. Appropriate Applications

These practices are implemented anywhere sediment is tracked from the project site onto public or private paved roads, typically at points of egress.

III. Standards and Specifications

A. Do not use kick brooms or sweeper attachments.
B. Visible sediment tracking shall be swept and vacuumed on a daily basis.
C. Do not sweep up any unknown substance or any object that may be potentially hazardous
D. Adjust brooms frequently; maximize efficiency of sweeping operations.
E. After storm drain protection measures are implemented, and sweeping is finished, the street may be washed down.

BMP 2 Water Conservation Practices

I. Definition and Purpose

Water conservation practices are activities that use water during the construction of a project in a manner that avoids causing erosion and/or the transport of pollutants offsite.

II. Appropriate Applications

A. Water conservation practices are implemented wherever water is used.
B. Applies to all construction projects.

III. Standards and Specifications

A. Keep water equipment in good working condition.
B. Repair water leaks promptly.
C. Do not use water or toxic agents to clean construction areas. Paved areas shall be swept and vacuumed.
D. Direct non-contaminated construction water runoff to areas where it can soak into the ground.
E. Apply water for dust control in accordance with the Caltrans Standard Specifications.

BMP 3 Dewatering Operations

I. Definition and Purpose

Dewatering operations are practices that manage the discharge of pollutants from groundwater and accumulated precipitation dewatering operations. This section does not apply to work within watercourses, where other, more specific, rules apply.

II. Appropriate Applications

A. Removal of uncontaminated groundwater.
B. Removal of accumulated rainwater from work areas.

III. Standards and Specifications

A. Contractor shall provide 48 hours notification to the Engineer of planned discharges.
B. Discharges must comply with regional and watershed-specific discharge requirements.
C. Ensure that dewatering discharges do not cause erosion at the discharge point.
D. A filtration device may be substituted for a desilting basin or sediment trap if the Contractor can demonstrate, to the Engineer's satisfaction, that the filtration device provides equivalent or greater removal of suspended solids than the basin.
E. Filter bags may be used for small-scale dewatering operations.

BMP 4 Paving and Grinding Operations

I. Definition and Purpose

Procedures that minimize pollution of storm water runoff during paving operations, including new paving and preparation of existing paved surfaces for overlays.

II. Appropriate Applications

These procedures are implemented where paving, surfacing, resurfacing, or sawcutting, may pollute storm water runoff or discharge to the storm drain system or watercourses.

III. Standards and Specifications

A. Substances used to coat asphalt transport trucks and asphalt spreading equipment shall not contain soap and shall be non-foaming and non-toxic.
B. Place drip pans or absorbent materials under paving equipment while not in use, to catch and/or contain drips and leaks. See also "Liquid Waste Management".

C. When paving involves asphaltic concrete (AC), the following steps shall be implemented to prevent the discharge of grinding residue, uncompacted or loose AC, tack coats, equipment cleaners, or unrelated paving materials.
   1. Do not wash sand or gravel from new asphalt into storm drains, streets, and creeks. Sweeping or other means of removal from the site shall be utilized.
   2. AC grindings, pieces, or chunks used in embankments or shoulder backing must not be allowed to enter any storm drains or watercourses.
   3. Collect and remove all broken asphalt and recycle when practical; otherwise, dispose in accordance with the Caltrans Standard Specification 7-1.13.
   4. Any AC chunks and pieces used in embankments must be placed above the water table and covered by at least 0.3m (1 ft) of material.
   5. Use only non-toxic substances to coat asphalt transport trucks and asphalt spreading equipment.

D. Drainage inlet structures and manholes shall be covered with filter fabric or tape during application of seal coat, tack coat, slurry seal, and/or fog seal.

E. Seal coat, tack coat, slurry seal, or fog seal shall not be applied if rainfall is predicted to occur during the application or curing period.

F. Clean asphalt coated equipment off-site. When cleaning dry, hardened asphalt from equipment, manage hardened asphalt debris as described in "Solid Waste Management". Any cleaning on site shall follow the section of this specification "Vehicle and Equipment Cleaning".

G. Do not wash sweepings from exposed aggregate concrete into a storm drain system. Collect and return to aggregate base stockpile, or dispose of properly.

H. Allow aggregate rinse to settle. Then, either allow rinse water to dry in a temporary pit as described in "Concrete Waste Management", or pump the water to the sanitary sewer if allowed by the local wastewater authority.

I. Do not allow saw-cut Portland Concrete Cement (PCC or AC) slurry to enter storm drains or watercourses. Residue from grinding operations shall be picked up by means of a vacuum attachment to the grinding machine, shall not be allowed to flow across the pavement, and shall not be left on the surface of the pavement. See also the sections of this specification "Concrete Waste Management", and "Liquid Waste Management".

J. When approved by the Engineer, stockpile material removed from roadways shall be kept away from drain inlets, drainage ditches, and watercourses.

K. Do not transfer or load bituminous material near drain inlets, the storm water drainage system or watercourses.

BMP 5 Illicit Connection/Illegal Discharge Detection and Reporting

I. Definition and Purpose

Procedures and practices designed for construction contractors to recognize illicit connections or illegally dumped or discharged materials on a construction site and report incidents to the Engineer.

II. Appropriate Applications

Illicit connection/illegal discharge detection and reporting is applicable anytime an illicit discharge is discovered or illegally dumped material is found on the construction site.

III. Standards and Specifications

A. Contractor shall inspect the site before beginning the job for evidence of illicit connections or illegal dumping or discharges, and shall promptly notify the Project Engineer of such conditions.
B. Contractor shall inspect the site regularly during project execution for evidence of illicit connections or illegal dumping or discharges.
C. Contractor shall observe site perimeter for evidence or potential of illicitly discharged or illegally dumped material that may enter the job site.
D. Contractor shall inspect the site regularly during the project for pungent odors coming from the drainage systems.
E. Contractor shall inspect the site regularly for discoloration or oily substances in the water or stains and residues detained within ditches, channels or drain boxes.
F. Contractor shall inspect the site regularly for abnormal water flow during the dry weather season.
G. Contractor shall inspect the site regularly for unusual flows in subdrain systems used for dewatering.
H. Contractor shall inspect the site regularly for excessive sediment deposits, particularly adjacent to or near active off-site construction projects.

BMP 6 Potable Water/Irrigation

I. Definition and Purpose

Potable Water/Irrigation consists of practices and procedures to reduce the possibility for the discharge of potential pollutants generated during discharges from irrigation water lines, landscape irrigation, lawn or garden watering, planned and unplanned discharges from potable water sources, water line flushing, and hydrant flushing.

II. Appropriate Applications

Implement this Policy whenever the above activities or discharges occur at or enter a construction site.

III. Standards and Specifications

A. Where possible, direct water from off-site sources around or through a construction site in a way that minimizes contact with the construction site.
B. Shut off the water source to broken lines, sprinklers, or valves as soon as possible to prevent excess water flow.
C. Protect downstream storm water drainage systems and watercourses from water pumped or bailed from trenches excavated to repair water lines using storm drain inlet protection measures.
D. Inspect irrigated areas within the construction limits for excess watering. Adjust watering times and schedules to ensure that the appropriate amount of water is being used and to minimize runoff.
E. Repair broken water lines as soon as possible or as directed by the Engineer.

BMP 7 Vehicle and Equipment Cleaning

I. Definition and Purpose

Procedures and practices used to minimize or eliminate the discharge of pollutants from vehicle and equipment cleaning operations to storm drain system or to watercourses.

II. Appropriate Applications

These procedures are applied on all construction sites where vehicle and equipment cleaning is performed.

III. Standards and Specifications

A. On-site vehicle and equipment washing is prohibited.
B. Cleaning of vehicles and equipment with soap, solvents or steam shall not occur on the project site unless the Engineer has been notified in advance and the resulting wastes are fully contained and disposed of outside the street right-of-way in conformance with the provisions in Section 7-1.13 of the Caltrans Standard Specifications. Resulting wastes shall not be discharged or buried within the street right-of-way.
C. Vehicle and equipment wash water shall be contained for percolation or evaporative drying away from storm drain inlets or watercourses and shall not be discharged within the street right-of-way.

D. All vehicles/equipment that regularly enter and leave the construction site must be cleaned off-site.
E. When vehicle/equipment washing/cleaning must occur on-site, and the operation cannot be located within a structure or building equipped with appropriate disposal facilities, the outside cleaning area shall have the following characteristics:
    1. Located away from storm drain inlets, drainage facilities, or watercourses.
    2. Paved with concrete or asphalt and bermed to contain wash waters and to prevent run-on and runoff.
    3. Configured with a sump to allow collection and disposal of wash water.
    4. Wash waters shall not be discharged to storm drains or watercourses.

BMP 8 Vehicle and Equipment Fueling

I. Definition and Purpose

Procedures and practices to minimize or eliminate the discharge of fuel spills and leaks into the storm drain system or to watercourses.

II. Appropriate Applications

These procedures are applied on all construction sites where vehicle and equipment fueling takes place.

III. Standards and Specifications

A. On-site vehicle and equipment fueling shall only be used where it's impractical to send vehicles and equipment off-site for fueling.
B. When fueling must occur on-site, the contractor shall select and designate an area to be used, subject to approval of the Engineer.
C. Equipment being fueled shall never be left unattended.
D. Absorbent spill clean-up materials and spill kits shall be available in fueling areas and on fueling trucks and shall be disposed of properly after use. The contractor shall notify the personnel performing fueling of the location of cleanup materials and spill kits.
E. Drip pans or absorbent pads shall be used during vehicle and equipment fueling, unless the fueling is performed over an impermeable surface in a dedicated fueling area.
F. Dedicated fueling areas shall be protected from storm water run-on and runoff, and shall be located at least 15 m (50') from downstream drainage facilities and watercourses. Fueling must be performed on level-grade areas.
G. Nozzles used in vehicle and equipment fueling shall be equipped with an automatic shut-off to control drips. Fueling operations shall not be left unattended.

H. Protect fueling areas with berms and/or dikes to prevent run-on, runoff, and to contain spills.
I. Use vapor recovery nozzles to help control drips as well as air pollution where required by Air Pollution Control District (APCD).
J. Fuel tanks shall not be "topped off."
K. Vehicles and equipment shall be inspected by the contractor on each day of use for leaks. Leaks shall be repaired immediately or problem vehicles or equipment shall be removed from the project site.
L. Absorbent materials shall be used on small spills instead of hosing down or burying techniques.
M. Mobile fueling of construction equipment throughout the site shall be minimized. Whenever practical, equipment shall be transported to the designated fueling area.

BMP 9 Vehicle and Equipment Maintenance

I. Definition and Purpose

Procedures and practices to minimize or eliminate the discharge of pollutants to the storm drain system or to watercourses from vehicle and equipment maintenance procedures.

II. Appropriate Applications

These procedures are applied on all construction projects where an on-site yard area is necessary for storage and maintenance of heavy equipment and vehicles.

III. Standards and Specifications

A. Drip pans or absorbent pads shall be used during vehicle and equipment maintenance work that involves fluids, unless the maintenance work is performed over an impermeable surface in a dedicated maintenance area.
B. All fueling trucks and fueling areas are required to have spill kits and/or use other spill protection devices. Contractor instructs all personnel involved in fueling operations in proper use of spill kits and related devices.
C. Dedicated maintenance areas shall be protected from storm water run-on and runoff, and shall be located at least 15 m (50') from downstream drainage facilities and watercourses.
D. Absorbent spill clean-up materials shall be available in maintenance areas and shall be disposed of properly after use. Substances used to coat asphalt transport trucks and asphalt-spreading equipment shall be non-toxic. Drainage inlet structures and manholes shall be covered with filter fabric when seal coat, tack coat, slurry seal, or fog seal is applied to adjacent surfaces.
E. Use off-site maintenance facilities.
F. Properly dispose of used oils, fluids, lubricants and spill cleanup materials.
G. Do not dump fuels and lubricants onto the ground.
H. Do not place used oil in a dumpster or pour into a storm drain or watercourse.

I. Properly dispose of or recycle used batteries.
J. Do not bury used tires.
K. Repair leaks of fluids and oil immediately.
L. Provide spill containment dikes or secondary containment around stored oil and chemical drums.
M. Vehicles and equipment shall be inspected on each day of use. Leaks shall be repaired immediately or the problem vehicle(s) or equipment shall be removed from the project site.
N. Inspect equipment for damaged hoses and leaky gaskets routinely. Repair or replace as needed.

BMP 10 Stockpile Management

I. <u>Definition and Purpose</u>

Procedures and practices to reduce or eliminate pollution of storm water from stockpiles of soil, and paving materials such as Portland cement concrete (PCC) rubble, asphalt concrete (AC), asphalt concrete rubble, aggregate base, aggregate sub-base or pre-mixed aggregate and asphalt binder (also called “cold mix” asphalt).

II. <u>Appropriate Applications</u>

Implemented in all projects that stockpile soil and paving materials.

III. <u>Standards and Specifications</u>

A. Protection of stockpiles is a year-round requirement.
B. Locate stockpiles away from concentrated flows of storm water, drainage courses, and inlets.
C. Protect all stockpiles from silt run-off by using a temporary perimeter sediment barrier such as silt fences, sandbag barriers, or straw wattles (fiber rolls).
D. During the rainy season, soil stockpiles shall be covered or protected with soil stabilization measures and a temporary perimeter sediment barrier at all times.
E. During the non-rainy season, soil stockpiles shall be either covered or protected with a temporary perimeter sediment barrier prior to the onset of precipitation.
F. Stockpiles of Portland cement concrete rubble, asphalt concrete, asphalt concrete rubble, aggregate base, or aggregate sub-base shall be either covered or protected with a temporary perimeter sediment barrier prior to the onset of precipitation.
G. Stockpiles of “cold mix” shall be placed on and covered with plastic or comparable material prior to the onset of precipitation.

BMP 11 Spill Prevention and Control

I. Definition and Purpose

These are procedures and practices implemented to prevent and control spills in a manner that minimizes or prevents the discharge of spilled material to the drainage system or watercourses.

II. Appropriate Application

This Policy applies to all construction projects. Spill control procedures are implemented anytime chemicals and/or hazardous substances are stored. Substances may include, but are not limited to:

A. Fuels
B. Lubricants
C. Other petroleum distillates

III. Standards and Specifications

A. To the extent that it doesn't compromise clean up activities, spills shall be covered and protected from storm water run-on during rainfall.
B. Spills shall not be buried or washed with water.
C. Water used for cleaning and decontamination shall not be allowed to enter storm drains or watercourses and shall be collected and disposed of in accordance with "Liquid Waste Management".
D. Water overflow or minor water spillage shall be contained and shall not be allowed to discharge into drainage facilities or watercourses.

IV. Clean up and Storage Procedures

A. Minor spills typically involve small quantities of oil, gasoline, paint, etc. which can be controlled by the first responder at the discovery of the spill.
B. Use absorbent materials on small spills. Do not hose down or bury.
C. Semi-significant spills still can be controlled by the first responder along with the aid of the other personnel such as laborers and the foreman, etc. This response may require the cessation of all other activities.
D. Clean up spills immediately.
E. If the spill occurs on paved or impermeable surfaces, clean up using "dry" methods (absorbent materials, cat litter and/or rags). Contain the spill by encircling with absorbent materials and do not let the spill spread widely.
F. If the spill occurs in dirt areas, immediately contain the spill by constructing an earthen dike. Dig up and properly dispose of contaminated soil.
G. If the spill occurs during rain, cover spill with tarps or other material to prevent contaminating runoff.

BMP 12 Solid Waste Management

I. Definition and Purpose

These are procedures and practices to minimize or eliminate the discharge of pollutants to the drainage system or to watercourses as a result of the creation, stockpiling, and removal of construction site wastes.

II. Appropriate Applications

A. Solid wastes include but are not limited to:
   1. Construction wastes including brick, mortar, timber, steel and metal scraps, pipe and electrical cuttings, non-hazardous equipment parts, Styrofoam and other materials used to transport and package construction materials.
   2. Highway planting wastes, including vegetative material, plant containers, and packaging materials.
   3. Litter, including food containers, beverage cans, coffee cups, paper bags, plastic wrappers, and smoking materials, including litter generated by the public.

III. Standards and Specifications

A. Littering on the project site shall be prohibited.
B. To prevent clogging of the storm drainage system, litter and debris removal from drainage grates, trash racks, and ditch lines shall be performed weekly.
C. Trash receptacles shall be provided in the Contractor’s yard, field trailer areas, and at locations where workers congregate for lunch and break periods.
D. Litter from work areas within the construction limits of the project site shall be collected and placed in watertight dumpsters at least weekly regardless of whether the litter was generated by the Contractor, the public, or others. Collected litter and debris shall not be placed in or next to drain inlets, storm water drainage systems or watercourses.
E. Storm water run-on shall be prevented from contacting stored solid waste through the use of berms, dikes, or other temporary diversion structures or through the use of measures to elevate waste from site surfaces.
F. Solid waste storage areas shall be located at least 15 m (50’) from drainage facilities and watercourses and shall not be located in areas prone to flooding or ponding.
G. Dumpster washout on the project site is not allowed.
H. Toxic liquid wastes (used oils, solvents, and paints) and chemicals (acids, pesticides, additives, curing compounds) shall not be disposed of in dumpsters.

BMP 13 Concrete Waste Management

I. Definition and Purpose

These are procedures and practices that are implemented to minimize or eliminate the discharge of concrete waste materials to the storm drain system or to watercourses.

II. Appropriate Applications

A. Concrete waste management practices are implemented on construction projects where concrete is used as a construction material or where concrete dust and debris result from demolition activities.
B. Where slurries containing Portland cement concrete (PCC) or asphalt concrete (AC) are generated, such as from saw cutting, coring, grinding, grooving, and hydro-concrete demolition.
C. Where concrete trucks and other concrete-coated equipment are washed on site, when approved by the Engineer. See also Vehicle and Equipment Cleaning.
D. Where mortar-mixing stations exist.

III. Standards and Specifications

A. PCC and AC waste shall not be allowed to enter storm drains or watercourses.
B. PCC and AC waste shall be collected and disposed of outside the highway right-of-way in conformance with section 7-1.13 of the Caltrans Standard Specifications or placed in a temporary concrete washout facility.
C. Below grade concrete washout facilities are typical. Above grade facilities are used if excavation is not practical.
D. Do not allow slurry residue from wet coring or saw-cutting AC or PCC to enter storm drains or receiving waters by:
    1. Placing temporary berms or sandbags around coring or saw-cutting locations to capture and contain slurry runoff.
    2. Placing straw bales, straw wattles (fiber rolls), sandbags, or gravel dams around inlets to prevent slurry from entering storm drains.
E. Vacuum slurry residue and dispose.
F. Temporary concrete washout facilities shall be located a minimum of 15 m (50 ft) from storm drain inlets, open drainage facilities, and watercourses, unless determined unfeasible by the engineer. Each facility shall be located away from construction traffic or access areas to prevent disturbance or tracking.
G. Temporary concrete washout facilities shall be constructed above grade or below grade at the option of the Contractor. Temporary concrete washout facilities shall be constructed and maintained in sufficient quantity and size to contain all liquid and concrete waste generated by washout operations.

H. Temporary washout facilities shall have a temporary pit or bermed areas of sufficient volume to completely contain all liquid and waste concrete materials generated during washout procedures.
I. Perform washout of concrete trucks in designated areas only.
J. Once concrete wastes are washed into the designated area and allowed to harden, the concrete shall be broken up, removed, and disposed of per "Solid Waste Management".
K. Temporary concrete washout facilities shall be constructed as shown on the plans, with a recommended minimum length and minimum width of 3 m (10'), but with sufficient quantity and volume to contain all liquid and concrete waste generated by washout operations. The length and width of a facility may be increased, at the Contractor's expense, upon approval of the engineer.
L. Existing facilities must be cleaned, or new facilities must be constructed and ready for use once the washout is 75% full.

BMP 14 Sanitary/Septic Waste Management

I. Definition and Purpose

Procedures and practices to minimize or eliminate the discharge of construction site sanitary/septic waste materials to the storm drain system or to watercourses.

II. Appropriate Applications

Sanitary/septic waste management practices are implemented on all construction sites that use temporary or portable sanitary/septic waste systems.

III. Standards and Specifications

A. Temporary sanitary facilities shall be located away from drainage facilities, watercourses, and from traffic circulation. When subjected to high winds or risk of high winds, as determined by the Engineer, temporary sanitary facilities shall be secured to prevent overturning.
B. Wastewater shall not be discharged or buried within the street right-of-way.
C. Ensure that sanitary/septic facilities are maintained in good working order by a licensed service.
D. Use only reputable, licensed sanitary/septic waste haulers.

BMP 15 Liquid Waste Management

I. Definition and Purpose

Procedures and practices to prevent discharge of pollutants to the storm drain system or to watercourses as a result of the creation, collection, and disposal of non-hazardous liquid wastes.

II. Appropriate Applications

Liquid waste management is applicable to construction projects that generate any of the following non-hazardous liquid wastes.

A. Drilling slurries and drilling fluids.
B. Grease-free and oil-free wastewater and rinse water.
C. Dredgings.
D. Other non-storm water liquid discharges not permitted by separate permits.

III. Standards and Specifications

A. Drilling residue and drilling fluids shall not be allowed to enter storm drains and watercourses and shall be disposed of outside the street right-of-way as approved by the engineer.
B. Liquid wastes generated as part of an operational procedure, such as water-laden dredged material and drilling mud, shall be contained and not allowed to flow into drainage channels or receiving waters prior to treatment.
C. Contain liquid wastes in a controlled area, such a holding pit, sediment basin, or portable tank.
D. Containment devices must be structurally sound and leak free.
E. Do not locate containment areas or devices where accidental release of the contained liquid can threaten health or safety, or discharge to water bodies, channels, ground water, or storm drains.
F. Capture all liquid wastes running off a surface that has the potential to affect the storm drainage system, such as wash water and rinse water from cleaning walls or pavement.
G. Do not allow liquid wastes to flow or discharge uncontrolled. Use temporary dikes or berms to intercept flows and direct them to a containment area for capture.
H. If the liquid waste is sediment laden, use a sediment trap for capturing and treating the liquid waste stream, or capture in a containment device and allow sediment to settle.
I. If necessary, further treat liquid wastes prior to disposal. Treatment may include, though is not limited to, sedimentation, filtration, and chemical neutralization.

SECTION 11.0

RIPARIAN REVEGETATION PLANNING AND IMPLEMENTATION

11.1 General

Streambank repair and channel maintenance projects may require stream channel modifications that include shaping, widening, deepening, straightening, and armoring. Many channel management projects also require building access roads for maintenance vehicles and other equipment. These construction activities can cause a variety of impacts to existing sensitive riparian and aquatic habitat that, depending on the selected design alternative, range from slight disturbances to complete removal of desirable woody vegetation and faunal communities. In urban areas within the SLO creek watershed, riparian vegetation often provides the only remaining natural habitat available for wildlife populations. For this reason, the biological consequences of channel maintenance projects must be seriously accounted, evaluated, and mitigated.

Revegetation will often be required on streambank repair and other channel maintenance projects to mitigate impacts to natural areas as determined by applications of the California Environmental Quality Act (CEQA), Section 1600-1607 of the California Fish and Game Code (Lake/Streambed Alteration Agreements), and Section 404 of the Clean Water Act (permitting to fill wetlands). This section of the DDM is intended to provide guidance for revegetation of riparian areas that are modified, created and/or managed for flood damage reduction, stream enhancement, and bank repair.

11.2 Design Approach

The benefits of riparian areas to human communities are many. Riparian areas provide significant ecological, flood control, water quality, agricultural, aesthetic, and recreational functions. Revegetation design must always recognize the potential of riparian areas to function as such and must attempt to accommodate and enhance this potential within the context of opportunities and constraints for particular projects.

11.2.1 Establishing Realistic Revegetation Goals

It is important for a biologist or revegetation specialist to participate in the initial assessment of opportunities and constraints for a project to help planners and engineers establish realistic revegetation goals. Maintenance supervisors and personnel responsible for the long-term management of a proposed project should also participate in revegetation goal setting. Revegetation goals that are incompatible with project opportunities and constraints will almost certainly fail.

The revegetation specialist should promote flexibility in hydraulic design to accommodate vegetation whenever possible. Channel designs that can assume high roughness values and allow for the largest possible rights-of-way usually provide the greatest revegetation opportunities. Generally, the more space available for vegetation and channel conveyance, the more the design process can attempt to preserve and enhance riparian values. In certain situations where space is highly constricted, channel designs that can incorporate some vegetation should be selected over those that cannot. Unfortunately, a lot of space that could be revegetated in flood control channel environments is often occupied by access roads and vehicle turnarounds. Wherever possible, sediment retention ponds and other sediment trapping structures that reduces the need for continuous road access along a channel should be considered during initial channel design phases.

11.2.2 Landscaping vs. Restoration

Because of the increasing scarcity of natural riparian areas, their significance to wildlife, and a growing public appreciation of their value, the bank stabilization or channel design should try to preserve and enhance existing ecologic values to the greatest extent possible. The intent of revegetation is to provide a plant cover for land that has been previously stripped of vegetation, and to restore, to some appreciable degree, the values associated with that original cover. Revegetation of riparian areas therefore implies that inherent ecologic values will be restored. This approach may differ from a design approach that focuses primarily on aesthetic issues, in a more traditional landscaping plan.

11.3 Design Concepts

Once realistic revegetation goals have been established for a project, design work can begin. Prior to creating revegetation plans and specifications, it is suggested that certain concepts regarding channel conditions, site issues and planting design be considered. These are discussed below.

11.3.1 Channel Considerations

- **Channel Capacity**

  Planting plans typically propose an optimal density of vegetation balanced against the channel capacity requirements for flood flow conveyance. Channel capacity, numbers of plants per segment or reach, and plant size at maturity are closely linked. If dense planting is a high priority for a project, then the bank repair or channel design should be adequately sized to accommodate dense vegetation. Site specific hydraulic modeling to determine appropriate planting densities for a channel should be conducted by using standard engineering methods.

- **Channel Erosion Potential**

  Channel erosion potential is an important consideration where flow velocities are high. Streambank design criteria requires protection for "stress areas" in channels that experience flow rates from above 2 meters per second (6 feet per second). Stress areas are locations such as junctions, transitions and channel bends, where hydraulic stress is greater than in a straight, uniform channel reach. Protection of non-stress areas in channels is required when flow velocities are above 2 meters per second (6 feet per second). While high flow velocities are usually addressed by engineering solutions that include rip-rap and other "hardscape" linings or revetments, biotechnical treatments using vegetation can also be effective to protect the channel from erosion. Because channels composed of earth and vegetation tend to provide more habitat values than channels lined with rip-rap or concrete, biotechnical approaches should be seriously considered. Whenever hydraulic conditions allow their use, a revegetation specialist should work closely with engineering professionals familiar with biotechnical approaches to help select appropriate plant materials.

- **Channel Planting Zones**

  Channel management projects should be designed to satisfy bank stability and flood conveyance requirements while maximizing the potential for preserving and enhancing ecological values. Different channel designs present different opportunities and constraints for revegetation. Where space constraints or requirements for channel surface treatments (i.e., armoring with rip-rap) limit channel design options, the amount of area available for planting and the variety of species that can be accommodated may be limited. Other situations allow channel designs that may accommodate lots of planting and plant diversity. These guidelines are intended to be used not only to facilitate the inclusion of revegetation planning into the channel design process, but also to assist resource managers desiring to enhance existing channels by planting appropriate quantities and species of vegetation.

  The recommendations of plant materials (as referenced in ***Table 11-1 through 11-5***) separates the channel into various zones (top of bank, toe, etc.) The zones represent a generalized gradient from relatively moist conditions (channel bed and toe of channel areas) to relatively dry conditions (upper bank areas). The selection of appropriate plant species for revegetating different channel types is based on the availability of differing suitable planting zones.

- **Short and Long-Term Channel Maintenance**

  The channel design process should include consideration of maintenance requirements and the environmental effects of maintenance policies. When vegetation is incorporated into channel designs, adequate funding and resources should be allocated to provide a effective plant establishment and long term maintenance program.

11.4 Planting Site Considerations

11.4.1 Soils

Consideration of the properties and condition of site soils is very important to determine the potential for establishing revegetation plants. Soils vary in fertility, and in characteristics that affect site drainage and root development. The fertility of most soils occurring in the SLO Creek watershed is generally adequate for establishing revegetation plant materials. Where fill is present, or where the upper layers of soil have been highly disturbed or removed from a site, testing for fertility may be warranted. In situations where soils have not been disturbed, or only slightly so, fertility will generally not be a significant issue.

Soil characteristics that affect drainage and root development often present more revegetation problems than do fertility issues. This soil movement can shear and damage the roots of revegetation plant materials. If large cracks develop on a site, effective irrigation of young revegetation plant materials may not be possible. Furthermore, clay soils subjected to construction activities can become severely compacted and difficult to cultivate. Because of these physical properties, establishing revegetation plants on heavy clay soils can be difficult. Special consideration should be given to selecting appropriate plant materials, irrigation methods and plant establishment procedures for insuring revegetation success on these soils. Plant losses can be minimized by planting larger container sizes and/or providing enough irrigation to prevent excessive soil shrinkage and cracking during the dry season.

Soils at construction sites such as bank stabilization and channel modification sites are often highly compacted as a result of grading and structural requirements. In many situations, soil preparation is necessary to facilitate successful reestablishment of vegetation. Typical soil preparation methods include ripping, disking and/or rototilling to improve soil porosity for greater gas exchange and water infiltration. Often organic soil amendments and fertilizers should be incorporated into soils disturbed during construction. The need to "open-up" or "loosen" soils in channel environments must be balanced against the potential for erosion.

Revegetation problems may also occur that are related to the stratification characteristics of alluvial sediments in natural, undisturbed soils. If stratification is pronounced, with layers of clays or other textures differing significantly from those above it, root and water penetration may be restricted. Such restrictions may limit the downward penetration of roots as well as the capillary rise of water into soil layers above the groundwater table. If sandy or gravelly soils are encountered, their low water holding capacities can make establishing revegetation species especially challenging.

Soil testing is seldom required for revegetation projects where the goal is to establish native vegetation that will be sustained by the available resources at a project site. In some situations certain tests may be necessary to determine the presence of toxins in the soil. If soil contaminants are suspected, testing should be conducted early enough in the planning process to review the test results, and consider measures for dealing with any problems that show up. If the soils at a site are severely disturbed as a result of construction and/or other activities, post disturbance sampling and testing may be necessary to determine fertility requirements and the need for correcting poor physical characteristics. Testing is especially necessary if subsoils are indiscriminately mixed with surface layers during cutting, filling and grading operations.

There are a number of commercial soil laboratories that will conduct tests on soil samples brought to them. Tests can be run separately or in combination for soil fertility and soil physical characteristics. Information contained in laboratory test results will be useful only if the revegetation site is properly sampled. Laboratory reports usually suggest methods for correcting deficiencies in soil fertility and soil structure for the purpose of growing specific agricultural crops. It is important to tell the laboratory what kind of plant materials will be grown on the site. Soil reports will recommend procedures to improve the site for the plant materials specified. Laboratory analysis for toxic chemicals are not routinely included in most agricultural soil tests. If toxic materials are suspected, it may be necessary to bring samples to a laboratory that specializes in the identification of toxic materials.

11.4.2 Irrigation Needs

Although soil characteristics are very important, it is mainly the availability of soil water that determines the success or failure of revegetation plantings. Native riparian vegetation requires soil moisture sufficiently in excess of that supplied by local rainfall. Natural sources of supply of "excess" water are from flooding and the capillary fringe above the groundwater table. The amount of soil water available for vegetation will vary from site to site depending on upstream environments and sources of water, the duration and height of stream flow, the depth to the water table, the amount and kind of stratification of alluvial sediments, soil texture, and other factors. Modifications made to channels for flood control can alter pre-project flow patterns and processes that make soil water available for vegetation.

The requirement for supplemental irrigation will depend on the amount and dependability of naturally available soil water and specific revegetation goals. On favorable sites, it may be possible to establish many revegetation plant species without supplemental irrigation. On other sites, only a few species will be appropriate for establishment without irrigation. On some sites, irrigation will be required to establish and sustain vegetation during the first few years.

For most revegetation efforts using native plants, the goal is for project sites to become self-sustaining as soon as possible. Irrigation systems should be used as a supplement to seasonal precipitation, only to establish plants. A typical establishment period lasts one to three years, after which irrigation systems can be removed or abandoned. In these situations, temporary irrigation systems are highly recommended, and high-cost permanent systems should be avoided.

Where vandalism is not a problem, the most practical systems to install and maintain are above ground systems or partially above ground systems. These usually have main lines that are buried, and above ground tubing or quick coupling valves that deliver water to plants though either emitters or quick disconnect sprinklers.

Irrigation design should include:

- Drawings that illustrate the location of water sources on or near the project site,
- The required materials and installation procedures for distributing water to plants,
- Estimates of the required frequency and quantities of irrigation water that should be applied seasonally.

On sites where existing native vegetation is to be preserved, special consideration needs to be given to irrigation under established native oak trees. Where native oaks occur, sprinkler irrigation should not be allowed anywhere within 10 meters (33 feet) of trunks. Only drought tolerant species, which require very minimal spot style irrigation during a brief establishment period, should be selected for planting within the drip lines of existing native oak trees.

11.4.3 Protection and Enhancement of Streamside Vegetation

On bank repair and channel modification projects where existing streamside vegetation will not appreciably affect the required channel capacity, or where streamside vegetation will not be directly impacted by channel alterations being considered, opportunities exist for enhancing these resources and affording them greater protection. Revegetation design should include protection and enhancement of streamside vegetation wherever it occurs on, or adjacent to project areas. Within project areas, the protection of existing native riparian species during construction should be carefully planned, usually by placement of temporary construction barrier fencing.

11.4.4 Access and Security Issues

The requirements for access paths or roads along stream channels will strongly influence plant design. Many flood control channel designs incorporate constructed roadways that allow heavy equipment access to the channel for sediment removal and/or reshaping operations. Plant selection along access roads needs to address long-term maintenance requirements for safe clearances and vehicular operation. Where access is required for recreational uses, security becomes a design issue that will affect plant selection, planting densities and long-term maintenance.

11.5 Planting Design Considerations

11.5.1 Choosing Reference Sites

Use of a reference site as a tool for biological design has great merit, but may not always be possible. Reference sites should be as close as possible to the stream reach being considered for revegetation. Preferably, reference sites should be on adjacent, undisturbed upstream and/or downstream reaches. Because many of the creek systems in the San Luis Obispo area have been exposed to continuous agricultural and urban impacts, much of their biological integrity has been severely eroded. Depending on the intensity and history of past and present impacts, different creek reaches in SLO exhibit different stages of recovery. It may even be desirable to select a stream reach outside of the watershed as a reference reach, if one is considered in the design process.

11.5.2 Species Composition and Habitat Structure

Two very important ecological considerations for planting design are successional trends and vegetation structure. Several studies have shown that early seral stages of riparian growth (i.e., emergent marsh habitat and willow thickets) favor larger numbers of certain resident and migrant birds than late successional stages. Larger mammals and other bird species may prefer later stages with mature stands of sycamores and dead or decadent cavity trees for nesting. The best habitats are often a mixture of the two, occurring near each other. This is seldom the case in the SLO Creek watershed. To create a variety of habitats and food resources for wildlife, a mosaic of seral stages is preferred. Such a mosaic should include percentages of life forms similar to those that occur on undisturbed reference reaches. The spatial arrangement of these life forms should offer wildlife patterns of vertical and horizontal structure similar to those found in reference sites. These concerns provide significant challenges to engineers who have to make channel design decisions based on requirements for hydraulic capacity and access issues. To successfully incorporate ecological concerns, channel design decisions need to be integrated with planting design goals.

Species composition can be designed to emulate reference areas by selecting similar kinds and numbers of life forms, similar percentages of deciduous and evergreen species, and similar relative densities of species.

The plant size distributions, canopy composition and relative densities of species in natural plant communities can serve as general guidelines for a planting design. However, these must be reconciled with other project considerations that also affect planting design, such as hydraulic requirements, aesthetics, access, and/or security issues.

Table 11-6
Recommended Species Composition Within
Riparian Forest Canopy Strata,
Oak Woodland, and Brackish Emergent Marsh

Strata Habitat	***Species Composition***	***Type of Species Within Each Statum***
Mixed Riparian Forest		
Overstory (20%)	Red Tree Willow (*Salix laevigata*)	20%
	Valley Oak (*Quercus lobata*)	20%
	Coast Live Oak (*Quercus agrifolia*)	25%
	California Bay (*Umbellularia californica*)	20%
	Walnut (*Juglans hindsii or J. californica*)	15%
Understory (60%)		
	California sagebrush, (*Artemisia california*)	5%
	Bush Monkeyflower, (*Diplacus auranticus*)	5%
	Coffeeberry (*Rhamnus californica*)	5%
	Fuchsia-flowered gooseberry, (*Ribes speciosum*)	5%
	Giant wild-rye, (*Elymus (Leymus) condensatus*)	10%
	Creeping wild-rye, (*Elymus (Leymus) triticoides*)	10%
	Coyote Bush (*Baccharis p.v. consanguinea)*	5%
	Wild Rose (*Rosa californica)*	5%
	Snowberry (*Symphoricarpos alba*)	5%
	Toyon (*Heteromeles arbutifolia)*	5%
	California Blackberry (*Rubus vitifolius)*	10%
	Arroyo Willow (*Salix lasiolepis)*	25%
	Box Elder (*Acer negundo ssp. Californica)*	5%
Oak Woodland (10%)		
	Valley Oak (Q. lobata)	65%
	Coast Live Oak (Q. agrifolia)	35%
Brackish Emergent Marsh (10%)		
	Common Tule (Scirpus acutus)	60%
	Alkali Bulrush (Scirpus robustus)	20%

11.5.3 Plant Spacing

Within the hydraulic capacity constraints of a selected channel design, plant spacing should mimic the spacing patterns of native species found on reference creeks. Mature, oak dominated cover occurs on several creek reaches in central coastal areas of California, which serve as good models for plant spacing decisions. This cover typically consists of trees in densities of 50 to 100 per acre, and shrubs in densities of 500 to 700 per acre. While a density model like this can influence plant spacing decisions, site specific hydraulic modeling must be conducted to determine the optimal allowable planting densities for a project. Since healthy plants increase in size over time, allowable densities will be higher for young plant materials than for older plants approaching their mature sizes. Because of mortality factors (especially on non-irrigated sites, or sites that receive minimal maintenance), it is often necessary to initially plant larger numbers of young trees and shrubs to achieve the final targeted densities of mature plants.

As a general rule for top of bank areas in most stream channel environments, large crowning trees can be spaced 6 to 7.5 meters (20 to 25 ft.) on center, small crowning trees at 3 to 4.5 meters (10 to 15 ft.), large shrubs at 1.5 to 2.5 meters (5 to 8 ft.) o.c., small shrubs at 1 to 1.5 meters (3 to 5 ft.) o.c., and grasses and ground cover plants at .5 to 1 meter (1.5 to 3 ft.) o.c., ***Figure 11-1*** illustrates an idealized spacing pattern for an upper bank area.

11.5.4 Aesthetic Considerations

The following basic aesthetic considerations should be incorporated into a revegetation design:

- Avoid straight-line planting, such as single rows of trees or shrubs.
- Group plants in clusters that tend to soften the typically linear appearance of channels.
- Select plants, which occur naturally together in local indigenous plant communities.
- Mix evergreen and deciduous plants.
- Include plants that have showy blossoms, fruits, and leaf color at various seasons.
- Include plants that attract wildlife.

11.5.5 Planting Stock

Revegetation plant materials typically include container grown stock, seeds, cuttings, poles, rhizomes, and mats or plugs. Planting container stock is usually the most successful method for revegetating riparian environments maintained for flood control. Cuttings, poles, and plugs can be collected and transplanted directly into certain project areas with some success. Different propagules work best for different species in different situations. Site-specific assessments need to be made to determine the best kinds of plant propagules suitable for a project. Selection criteria for propagule type suggested by the U.S. Army Corps of Engineers (1978) for use in marsh revegetation projects are as follows: availability and cost, collection and handling ease, storage ease, planting ease, presence of disease, elevation of the site, and the urgency of need for cover.

Special care should be taken to avoid contamination of native gene pools by not introducing species and/or subspecies capable of hybridizing with plants that occur naturally at a project site. Where possible, it is desirable to use native species indigenous to the San Luis Obispo area, and propagation materials should be collected from local sites. If this is not possible for certain species, materials can be collected from comparable areas in the Central Coast area. When collecting seed from a particular site, attempt to insure the greatest possible genetic diversity by including a large and diverse set of plants. Randomly collect from plants within a population and among different populations. Avoid collecting plants from areas with special limiting conditions (i.e., such as the presence of serpentine soils) unless the revegetation site has similar conditions. Because revegetation planting is best conducted during the fall and early spring, planning to insure availability of plant materials at these times is essential. Depending on plant material specifications for a revegetation project, lead-time for collecting and propagating suitable plants can be as high as two to three years.

The nursery industry typically supplies plant materials in 4, 19, 56-liter (1, 5 and 15-gallon) container sizes. Some native plant materials are available in these container sizes. Within the last several years, native plant materials have become available in containers that are more suitable for revegetation projects in environments that will receive minimal maintenance. They include leach tubes or Supercells 38 x 200 millimeters (mm) (1.5 "x 8"), Depots 63 x 254 mm (2.5" x 10"), Treepots 101 x 355 mm, 152 x 406 mm, and 203 x 457 mm (4" x 14", 6" x 16", and 8" x 18"), Treebands 57 x 127 mm (2.25" x 5") with open bottoms), rosepots 57 x 76 mm (2.25" x 3"), various grass plug pot sizes, and others. Selecting the right plant container sizes for a project depends on several factors. These include cost factors, site conditions and adaptability factors, availability of plant materials, and issues related to public perception of the project.

Selecting the right plant container sizes for a project depends on several factors. These include cost factors, site conditions and adaptability factors, availability of plant materials, and issues related to public perception of the project. There are differences in the cost and required duration of maintenance associated with different container sizes. Because small container plants are cheaper to buy than large container plants, and generally require less maintenance time to become established, using them can result in some cost savings.

Native plant materials are not always commercially available, and they are rarely available in the quantities required for most revegetation projects. Because of this, it is often necessary to specify plant material procurement procedures in a revegetation design. An increasing number of nurseries specialize in growing native plant materials for revegetation projects on a contract basis. If a project requires using plant materials propagated from vegetation growing on or near the project site, some of these nurseries will make arrangements to collect seeds, cuttings and other propagation materials from the area. Because of the lead-time necessary to collect propagules and grow revegetation plant materials (often one growing season or longer), procurement scheduling is critical to the successful implementation of any revegetation design.

11.5.6 Plant Selection Criteria

The process of selecting appropriate revegetation plant species should follow specific criteria established during the preliminary goal setting and design phases of a particular project. It is suggested that plant selection for creeks and flood control channel environments be based on the following basic criteria:

1. Channel design types;
2. Special characteristics that make plant species compatible or incompatible with the specific engineering and aesthetic goals for a project;
3. The ecological significance of plant species;
4. The type of maintenance plant species will receive after planting; and,
5. Access for channel maintenance.

By carefully considering established revegetation goals and the above criteria, lists of appropriate plant materials for specific flood control channel designs can be prepared.

11.5.7 Channel Design Types & Suitable Planting Zones

The availability of soil moisture is the primary limiting factor influencing plant establishment and distribution within a channel environment. Water availability is affected by a complex interdependent set of variables that include annual precipitation, soil type, infiltration and run-off, depth to groundwater, channel gradient, channel shape and size, bank slope, and exposure to solar radiation. Different plants usually occur in different zones of a creek system along a gradient of water availability. The channel bed will generally remain moist for a longer period of the year than upper bank areas, so plants that require greater moisture during the later part of the season will be located in or near the channel bed. Conversely, plants that are more drought-tolerant tend to be located higher up on the channel bank. While plants may have similar moisture requirements, they can differ regarding their tolerances to prolonged periods of inundation and their natural distribution within a channel reflects this.

Tables 11-1 and ***11-5*** show the suitability of each listed plant species for different planting zones. The zones represent a generalized gradient from relatively moist conditions (channel bed and toe of channel areas) to relatively dry conditions (upper bank areas). To create self-sustaining landscapes with minimal maintenance requirements (i.e., minimal irrigation), plant species should be selected according to the availability of suitable planting zones.

11.5.8 Special Plant Characteristics

Once a list of potential plant species is generated based on a preferred channel type and available planting zones, the list can be refined by considering special plant characteristics (**Figure 11-2**). Plant characteristics useful to consider for revegetation projects in channel environments include:

- *Establishment Potential* - Is the plant easily established? Does the plant require special or excessive maintenance to enable it to be sustained by the available resources at the planting site?
- *Life Form* - Is the plant a tree, shrub, low growing herb or grass?
- *Plant Size* - What is the plants expected height and width at maturity?
- *Longevity* - Is the plant long-lived?
- *Structural Integrity* - Does the plant break apart easily under natural stresses (i.e., does it shed large branches in storms or high winds)?
- *Availability* - Is the plant easily propagated and/or commonly available at native plant nurseries? Can propagules be easily obtained at local sites?
- *Invasiveness* - Does the plant have the potential to spread rapidly and overwhelm the rooting space and growth potential of other plants? Can the plant's Invasiveness cause damage to flood control structures within the channel?
- *Age* - Diverse uneven aged riparian woody vegetation provides stable channel corridor. Willows need to be maintained in locations such as this as specified in these Guidelines in order to maintain flood control capacity.
- *Erosion Control Potential* - Does the plant contribute significantly to soil stabilization?
- *Special Tolerances - Can the plant withstand periods of inundation, drought, shade, and/or high winds? Is the plant fire resistant?*
- *Aesthetic Value - Does the plant have attractive foliage, flowers and/or fruits?*
- *Toxicity - Is the plant poisonous to humans, livestock, pets and/or wildlife?*
- *Seasonal Leaf Retention - Is the plant deciduous or evergreen?*
- *Screening and Barrier Values - Does the plant present a significant barrier to access, visibility, wind, noise, dust, etc.?*
- *Wildlife Value* - Does the plant provide significant habitat opportunities and resources for wildlife species?

11.5.9 Ecological Considerations

Plant selection should always be site and project specific. Pre-project planning assessments should catalogue the kinds and distribution of habitats that occur at a site, and evaluate how proposed project alternatives will impact the environmental conditions that control plant diversity and distribution. The plant selection process needs to identify ecologically important plant species that can survive the special environmental conditions resulting from flood control channel modifications. Plant selection should also target the habitat requirements of wildlife found on reference sites. Selection should favor combinations of plant species that can accommodate similar numbers of birds, fish, insects, amphibians, reptiles, and mammals that occur on reference sites.

The ecological suitability of any plant species must be reconciled with the engineering requirements for particular projects. For example, shrubby, thicket-forming willows might be very significant ecologically, but their invasive, vigorous growth habit can impede flows and adversely affect a channel's capacity to carry targeted flood levels. Unless a project site allows for the design of a channel type and size that can accommodate potentially invasive species like willows, these plants should be avoided.

11.5.10 Maintenance Considerations

The most successful revegetation projects are those with carefully selected plants that perform well with the maintenance they receive. It is therefore necessary to determine the kind of maintenance that can be provided prior to selecting plants. Decisions regarding the kind of maintenance that can be provided for a project depend on revegetation goals, cost factors, supervision and personnel issues, and other matters. Whatever decisions are made, they should guide the plant selection process. The San Luis Obispo Creek Maintenance and Management Program presents detailed information on maintenance procedures.

11.5.11 Summary of Procedure for Developing a Plant List

Steps for developing a list of appropriate plants are outlined as follows:

> ***Step 1*****:** Determine what kind of wetland environments will be left undisturbed, or will be created by a flood control project (i.e., freshwater emergent marsh, brackish marsh, salt water marsh, riparian shrub/scrub, mixed riparian, etc.). Eliminate plant species that do not occur in the kind of wetland environment supported by the project design.
>
> ***Step 2*****:** Determine the preferred channel type(s) for the project site. Eliminate plants that are not suitable for the planting zones available in the selected channel type.
>
> ***Step 3:*** Select plant characteristics desirable for the project. Eliminate plant species that do not exhibit these characteristics, or eliminate plant species that have undesirable characteristics.

> ***Step 4:*** *Select plants suitable for the kind of maintenance that a project will receive. Eliminate* plant species that will not survive with this kind of maintenance or that are incompatible with the proposed access design.

The revegetation specialist will recognize that for most flood control projects, certain plant species exhibit characteristics that are significantly more desirable than others. These plants are typically easy to establish, are long-lived, have good structural integrity, high wildlife value, offer significant erosion control, are tolerant of drought, are relatively fire resistant, are attractive, and require little or no maintenance after a brief establishment period. Some of the plant species listed exhibit all these characteristics while others only exhibit a few.

11.6 Revegetation Implementation

11.6.1 Contractor Qualifications

Once revegetation plans and specifications have been reviewed and approved, bids for implementing the work can be solicited. The City/County will consider pre-qualifying contractors for some kinds of revegetation projects. A statement of qualifications (SOQ) should accompany any pre-bid pre-qualification submittal requirement. The contractor's qualifications should include experience working with native plant materials, and in riparian ecosystems. Minimal qualifying requirements for bidders should include the following:

A descriptive list of completed revegetation projects should accompany all bid proposals. The list should include past or current clients who can be contacted as references.

Licensed landscape contractors should have at least five years experience in planting, establishing and/or maintaining native plants on both irrigated and non-irrigated revegetation projects.

Preference should be given to experienced and reputable contractors that have completed riparian revegetation projects in the San Luis Obispo area or in similar areas of California.

11.6.2 Planning and Coordination

Prior to the commencement of any work, a meeting should be held by representatives of regulatory agencies, the contracting officer, the project developer or sponsor, and any contractors that will be working on or near the revegetation project site. The purpose of the meeting is to discuss work and inspection schedules and to thoroughly review the scope of any contract that could potentially affect the revegetation site. The meeting can serve to promote a clear understanding of all expectations and obligations associated with the revegetation site and related contracts.

Before crews start work on a revegetation site, the revegetation contractor and contracting officer (or a designated representative) should meet in the field to discuss, explain and clarify all plans and specifications associated with the revegetation contract.

11.6.3 Environmental Protection

Contract documents should clearly establish the responsibilities of the developer, general contractor and/or revegetation contractor regarding the protection of existing natural resources at a project site. Prior to commencement of any work, these resources should be clearly identified and marked in the field by a hydrologist, biologist, revegetation specialist, or other qualified environmental consultants. Specific contractual measures to protect existing natural resources should include the following:

- Prior to commencement of any construction activities, temporary protective fencing should be placed around all vegetation, soils and sensitive areas that are to be preserved at the project site.

- Grading or excavation should not occur within the driplines of any native tree, except where shown on the revegetation plans. The term dripline refers to the area of ground from the trunk of any tree to the point directly below the outermost tips of the branches of that tree.

- Revegetation site soils should not be compacted by any construction activities. Vehicular traffic should not be allowed on the revegetation site, especially when soils are wet. Vehicles should not be allowed within the dripline of any tree that is to be preserved.

- Site exposure to harmful substances should not be allowed. No storage or dumping of oil, gas, chemicals, or other substances that may be harmful to vegetation should occur at any location on a revegetation site.

- Existing native woody seedlings on a revegetation site should be protected during construction, and irrigated as necessary to promote establishment.

- Care should be taken to assure that site-grading earthwork does not disturb any area to be preserved. Silt fences, straw bales and/or other erosion control BMPs should be employed to prevent impacts to creeks. On projects that have specified goals for establishing a particular kind of grass cover; only straw from the specified grass species should be used as mulch to control erosion.

- All preservation zones should be clearly delineated on construction drawings, and referenced in the contract specifications. No entry, dumping or other disturbances in these zones should be allowed without formal written permission from appropriate regulatory agencies.

- Exotic vegetation on the site should be removed in accordance with approved revegetation goals, plans and specifications.

11.7 Project Planning and Scheduling

Timing for a revegetation project is critical. Early planning to insure availability of plant materials for fall planting is essential. Lead-time for plants that need to be contract grown can be one to two years (contract growing is often necessary because many native plants required for revegetation are not always commercially available). On certain project sites, effective pre-planning weed control can take an entire year or more. Fall is a much better time for planting and establishing vegetation than the summer. The best survival rates for plants planted on mid to lower creek banks are after the chance of flooding is past. Timing of grass seeding is also critical. Properly timed grass seeding is especially important where irrigation is not available, and where erosion control from grass growth is desired.

11.7.1 Planting Site Preparation

- **Soil Preparation**

  For sites that have not been adversely affected by construction activities or pre-project impacts, preparation of site soils is not generally necessary prior to planting revegetation plants. However, the potential for a successful revegetation project is greatly hindered on sites where soil compaction, poor drainage, loss of topsoil, and/or excessive ruderal or exotic vegetation occur. In cases where significant disturbances to existing soils are unavoidable, stockpiling of topsoils is often a valuable practice. This is especially true on sites where subsoils are unfavorable for revegetation. Subsoils should be ripped and cross-ripped prior to spreading stockpiled topsoil.

  Pre-project assessments of the grass and herbaceous cover growing in areas proposed for revegetation should identify weed species and prescribe methods for controlling them both before topsoils are stockpiled, and again after they are spread. Compacted soils may be rectified by ripping, disking and/or rototilling. On steep gradients where erosion may be a problem, tillage operations should be performed across-slope rather than up/down slope. Poor soil structure and permeability can be improved by incorporating organic soil conditioners into the top six to eight inches of the soil. Suitable amendments include chopped straw (free of seeds), mushroom compost, rice hulls, sawdust, ground fir bark, and/or other materials. Because of the high cost of these materials, soil conditioners are not generally recommended for most revegetation projects. However, their use on severely disturbed sites may significantly increase the initial survival percentage of revegetation plants. If revegetation goals include seeding, careful seedbed preparation will increase germination and establishment potential.

- **Removal of Herbaceous Weeds Prior to Planting**

  On sites where the existing grass and herb cover is to be retained, a 1.2 x 1.2 meters (4' x 4') zone should be cleared for each individual revegetation plant. If the existing cover is excessively tall and dense, mowing and/or light discing can facilitate clearing, planting and irrigation operations. Mowing should not occur if it has been determined that removal of high, residual cover will adversely affect certain wildlife species. While fire vulnerable dry grasses and herbs are generally discouraged in flood control channels, tall cover plant residues can serve to protect delicate revegetation plants from drying winds. The choice between leaving or removing all or part of the existing grass and herb cover will depend on wildlife habitat issues, revegetation goals, proposed plant establishment and maintenance practices, and long-term management goals.

  On sites where revegetation goals require the removal and replacement of existing cover plants, more intensive weed eradication methods can be employed to prepare the site for planting a specified cover of grasses and herbs (see discussion on grass seeding below). After all clearing, grading and disking (ripping and/or rototilling) is completed and irrigation systems have been installed, the planting area should be thoroughly irrigated to force germination of as many weed seeds as possible. Once significant weed growth is established, the area can be sprayed with a short-duration, broad spectrum, contact herbicide that will completely degrade before planting. This irrigation-herbicide treatment should be repeated a number of times over several months to facilitate further germination and killing of residual weed seeds. For sites where sprinkler irrigation is not possible (i.e., sites that rely upon seasonally available precipitation) herbicides should be applied in late October or early November after weeds emerge and begin to grow. A second spray treatment should be applied in early to mid spring depending on the timing of germination and growth of the weed species present.

  In situations where chemical weed control programs are not possible, several mechanical methods can be employed. They include repetitive mowing, cultivation, hand pulling, and light exclusion (i.e., covering the planting area with fabric or other materials that prevent germination and/or growth by excluding light). Annual cover plants can be reduced on a site by mowing them to a height of two to four inches in the spring when grasses begin to flower. For more effective control, mowing usually needs to be repeated once or twice during the growing season (from late March to mid June). Repeated cultivation during the growing season by either discing or rototilling can also effectively reduce annuals. However, cultivation is discouraged in soils that have large stores of viable weed seeds because repeated mixing of the soil can encourage their germination (i.e., cultivation moves buried weed seeds to zones within the soil where conditions favor their germination). While mechanical weed control methods are valuable in certain situations, they are usually much more labor intensive and expensive than using herbicides, and often less effective. In many situations, they can also be more disruptive to the environment.

- **Removal of Exotic Vegetation**

  The removal of exotic tree and shrub species is often required to reestablish native riparian vegetation at a site, and is usually best performed prior to planting. Depending on the growth habits of exotic trees and shrubs, it may be advantageous to leave certain non-invasive exotics on a site to protect some revegetation plants from harsh windy and/or sunny exposures. As revegetation plants become established, exotic trees and shrubs can be selectively removed over time. This is a good practice where large groves of exotic trees occur that provide some wildlife habitat values and other benefits. In these situations, selected patches of trees can be removed gradually over a period of several years to protect the site until replacement plantings become established. Also, certain trees can be killed and left in place as "snags" for wildlife. Procedures for exotic tree and shrub removal are described as follows:

  After a qualified restoration specialist identifies all exotic shrubs and trees and prepares a removal plan, work can commence. Tree cutting and removal should be performed in such a way that trees are felled into natural openings or other areas to be cleared. Care must be taken to not damage existing native vegetation. Any branches of native trees that are damaged during exotic tree removal should be pruned back to a branch as near as possible to the break point by a well-selected thinning cut. Tree and shrub stumps of exotic species such as poplar, eucalyptus and pyracantha should be treated with a stump killer. Re-spouting can be controlled with glyphospate herbicides (Roundup or Rodeo), if approved for site conditions, or removed by hand. To promote natural degradation, the stumps of non-sprouting species with ground level trunk diameters less than 304 millimeters (12 inches) can be treated by drilling 25.4-milliammeter (1-inch) diameter holes 152 millimeters (6 inches) deep and 101 millimeters (4 inches) on center. All branches and debris from plant removal operations should be removed from the project site, chipped and spread, or otherwise left on the site as directed in the removal plan.

  As mentioned above, it may be advantageous to kill exotic overstory trees and leave them standing as snags for wildlife. This can be accomplished by girdling. Girdling cuts should be made late in the season to delay and diminish sprouting. Control sprouting with herbicides. If species of Populus (poplar) are cut down or girdled, be prepared to respond to aggressive root sprouting.

11.8 Planting Layout

Layout of plant materials should follow approved revegetation plans and specifications as closely as possible. Prior to installation of any plant materials, the contractor should place flags or markers at each planting site, using a different color and/or number for each revegetation species. Areas where specified seed mixtures are to be planted can also be marked out. The contractor should provide the contracting officer and/or a designated project inspector with an index correlating the flags or markers with the type of plants that will be planted. The revegetation designer, landscape architect, and/or project inspector should field check and approve the marked layout, and make any adjustments in planting locations and/or numbers prior to installation. The project inspector may also wish to check the quality of the revegetation plant materials at this time.

11.9 Planting Woody Revegetation Plant Materials

Woody revegetation planting stock can be planted from depots/leech tubes, standard nursery container stock 4, 19, or 57-liter (1, 5, or 15-gallon) containers, cuttings, and poles.

11.9.1 Planting Container Plants

- **Depots and Leach Tubes**

  Holes for depots and leach tubes may be hand dug or augured. In compacted soils it is beneficial to dig a wide hole for each plant (i.e., five to ten times the diameter of the depot or leech tube). Depth should not exceed more than twice the length of the container unless it is required to penetrate shallow hardpans. The plant should be carefully removed from its container and any curled, bent or broken roots should be removed with a sharp, clean pruning tool. Most of the soil should be returned to the planting hole and lightly firmed to prevent settling. Before completely filling the hole, the plant should be held over it at the appropriate planting level (i.e., the point where the root crown is level with the original grade level). Finish backfilling the hole while keeping the plant at the appropriate planting level, and lightly compress the backfill around the plant. Fertilizer can be applied by using one-third ounce (one teaspoon) of Osmocote 14-14-14 (or equivalent) slow release granular fertilizer per planting site, or by placing a slow release fertilizer tablet (Agriform or equivalent) on either side of the plant.

  Protection from herbivores is necessary at certain revegetation sites. This can be accomplished by using protective screens, planting collars, or manufactured tree shelters. Root collars can be made from one-quart cottage cheese containers with the bottoms cut out. These provide some protection from gophers. Screens for protecting above ground stems and foliage can be made from 1/20-inch mesh aluminum window screen material (see planting details). A good method of protecting young trees from both herbivores and wind desiccation is by using translucent polypropylene tree shelters (TUBEX Treeshelters or equivalent). Tree shelters, although initially expensive to purchase, are a cost effective alterative to screening and root collars, because they require less labor to install. Tree shelters have been shown to provide excellent protection from herbivores and to increase plant growth and survival rates. Tree shelters also serve to effectively mark revegetation plants, protecting them from vehicular traffic, mowing machines, herbicide sprays, weed whipping, and other potentially harmful maintenance operations.

Placement of weed control fabric or matting can significantly improve the survival of revegetation plants, and should be required where competition from weeds is anticipated. A .9 x .9 meter (3' x 3') mat should be placed around each plant. The mat can be secured to the ground with 152-millimeter (6-inch), U-shaped staples.

- **Planting Container Stock**

Planting holes for larger container planting stock should be at least two times as large in diameter as the container and one and one-half times as deep. The root ball of container plants should be set at 25.4-millimeter (1-inch) above finish grade. Backfill soil should be tamped solidly around the roots. After holes have been backfilled 2/3 full, the plant should be thoroughly watered to settle the soil and insure good soil/root contact before placing the remainder of the planting soil. A slow release fertilizer (i.e., agriform tablets or Osmocote granules) should be placed around the root ball per the manufacturer's specifications. A watering basin should be constructed around each plant by forming a 101-millimeters (4-inch) high circular berm 304 millimeters (12 inches) from the edge of the root ball. All plants should be watered immediately after planting. A .9 x .9 meter (3' x 3') weed control fabric mat should be placed and securely fastened to the ground around each plant.

- **Planting Cuttings and Poles**

Willows cuttings and cottonwood poles can be planted at a relatively low cost on many revegetation projects. Willow cuttings should be approximately 609 to 914 mm (24 to 36 inches) long and a minimum of 12 millimeters (½-inch) in diameter. Cottonwood poles up to 2 meters (6.6 ft.) in length can be installed in pre-drilled holes, and backfilled with the native soil. Pilot holes for willow cuttings can be made by driving a steel stake into the ground to a depth of 203 mm. (8inches) or more. Cuttings can be planted by inserting them into the pilot holes and foot-tamping soil around them. In soft, moist soils, willow cuttings can be pushed into the soil or hammered down with a rubber mallet. No more than 106 to 152 mm (4 to 6 inches) of a cutting should be exposed at the surface of the soil. Willow cuttings can be planted densely .9 to 1.2 meters (3 to 4 feet on center) to help stabilize banks and prevent erosion. Cottonwood poles should be at least 1.5 meters (5 feet) long with a diagonally cut base at least 51 mm (2 inches) in diameter and a top at least 5/8-inch in diameter. Poles should be taken and planted during the dormant season (December/January). Prune off all side branches and insert poles in a augured hole to a depth of approximately two-thirds of their length. All poles must be planted with the buds pointing up. Best sprouting results occur when plant materials are installed on site within eight hours of cutting. They can be kept fresh at the job site by placing them in the streambed. Alternatively, provisions for proper storage should be made. Materials should be fresh, dormant and non-desiccated when installed.

11.10 Wetland Plants

Marsh plants usually will become established in wetland areas by natural invasion if circulation is good, wildlife species are abundant, and good sources of seed and vegetative propagules are close. Freshwater marsh species can be established from seed and/or transplanted stem and root masses (i.e., *Scirpus, Juncus*, and *Carex* species transplant well from root masses). Another good way to "transplant" marsh vegetation is to transport muds collected from existing well-vegetated marshes to a revegetation project site, inoculating areas where flow and depth conditions are suitable for the development of marsh vegetation. Newly transplanted muds and plant propagules can be held in place by various bioengineering techniques where erosion or high flows are anticipated.

Salt water marsh plants such as alkali heath and fat-hen will colonize a project site naturally if the site is near existing populations of these species. Other plants like pickleweed, cord grass and salt grass will also invade a new site if conditions are favorable. While artificial propagation is generally unwarranted, it may be necessary in some cases to propagate these species. Due to legal issues surrounding salt marsh and wetland habitats, propagules should only be collected from approved collection sites. Collected materials may be divided and grown in nurseries for future use, or they may transplanted directly into revegetation sites.

11.11 Seeding Grasses

Revegetation goals for seeding grasses and herbs should be realistically related to a site's potential for plant establishment success. Where soil compaction, poor drainage, loss of topsoil, and/or excessive ruderal or exotic vegetation occur, the potential for successfully establishing seeded grasses and herbs is greatly hindered. In general, the success of seeding depends on the following factors: the type and condition of site soils; the composition and density of the existing cover; the soil seed bank; initial seedbed preparation; the kinds of species selected for seeding; seeding rates and seed quality; the timing of seeding; the availability and use of supplemental irrigation, or if not available, the amount and duration of seasonal precipitation; the percentage and evenness of germination; and, the degree of pre and post-planting weed control maintenance. Because establishing seeded cover plants can require a considerable investment in site preparation and follow-up maintenance, setting clear and realistic revegetation goals for seeding can save money and increase project success.

11.12 Erosion Control Seeding

Revegetation plans often include specifications for seeding grasses and herbs for erosion control. In the past, because of their relatively low cost and availability, specifications for erosion control seeding typically included fast germinating, quick-to- establish annual grass species such as annual rye (*Lolium multiflorum*), Zoro fescue (*Vulpia myuros*), blando brome (*Bromus hordeaceus* - formerly called *Bromus mollis*), and cereal oats and barley (*Avena sativa* and *Hordeum vulgare*, respectively). Many of these grasses are highly competitive with native grasses, and some (i.e, annual rye) have recently been shown to actually suppress the establishment of native plants on revegetation sites. Annual grasses also produce a lot of combustible dry matter that may require costly mowing maintenance to reduce fire hazards. For these reasons, a project proponent may elect to use native grasses for establishment of gravel cover and for permanent erosion control.

Some projects may require establishment of native grasses, and the following guidelines are provided. Several species of native perennial grass suitable for erosion control have become commercially available in larger quantities; they should be used instead of the annual grass species mentioned above. One of the most effective ways to satisfy erosion control seeding requirements is to use straw bailed as a byproduct of harvesting native grass seed. The straw of several commercially available native grass species often retains up to .9 kilograms (2 pounds) of seed per bale. Spreading native grass straw at a rate of two bales/90 square meters (1,000 square feet - approximately 3.5 tons/acre) can provide good erosion control protection with the added benefit of seeding selected native grasses. By using only native straw, compensation for money that might be spent on buying expensive native grass seed used in conjunction with more conventional commercially available straws (i.e., wheat, barley, oat, or rice) can be achieved. Native straw mulch can be purchased from several growers of native grasses. Straw is usually available for the following species: California fescue (*Bromus carinatus*), slender wheatgrass (*Agropyron trachycaulum majus*), meadow barley (*Hordeum brchyantherum* and *Hordeum californicum var californicum*), Molate fescue (*Festuca rubra*), blue wildrye (*Elymus glaucus*) and others.

11.13 Grassland Conversion and Restoration

Some revegetation plans specify a grassland restoration approach that calls for the removal of existing non-native annuals and replacement with native perennial grasses. Grassland restoration in California is relatively new; many projects have been tried, but studies that document successful performance of native grasses are rare. Appropriate cultivars and establishment methods are still very experimental. In spite of this, grassland restoration is often assumed to be a worthy revegetation goal, and more and more revegetation plans include specifications for seeding native grasses. Investing in the establishment of a permanent cover of perennial bunchgrasses can significantly improve the appearance of a channel and save the long-term maintenance costs usually allocated for ongoing management of ruderal herbaceous species and fire vulnerable annual grasses.

Several species of native perennial grasses occur in small numbers in San Luis Obispo area grasslands. They provide nesting habitat and food resources for wildlife and are valuable soil stabilizers. However, the temptation to type convert areas dominated by annual non-native grasses to grasslands dominated by native perennial bunchgrasses must be tempered by the realization that currently accepted procedures for site preparation, seeding and establishment are not only extremely expensive, but they are also untested. Certain species and cultivars are more promising for managed channel environments than others based on answers to the following questions.

1. Does the species compete well with ruderal herbaceous weeds and annual grasses?

2. Does the species become established with minimal maintenance efforts and costs?

3. Does the species' growth habit impede flows, or otherwise increase channel roughness to unacceptable levels?

4. Can the grass withstand erosive flows? Does it regenerate and perform well after flood events?

5. Does the growth habit of the grass increase fire hazards? Will the grass require more or less mowing to decrease fire hazards than the existing annual cover?

11.14 Seeding Methods

The best time to seed in San Luis Obispo is during late fall or early spring when temperature and moisture conditions are favorable. Do not seed during the winter when cold temperatures inhibit germination and root growth, or during the summer when hot temperatures and wind can dry out the seedbed. Seeding should follow soil and seedbed preparation as soon as possible. For large sites the best method of seeding is by drilling. For very large areas with steep slopes not accessible by drills, hydroseeding can be an effective method. Hydroseeding is accomplished by pumping a slurry of seed, water and mulch (optional) from a tank towed behind a truck, and spraying the mixture through a high-pressure nozzle onto a prepared site. For smaller sites where steep slopes, existing plants or other conditions make it difficult to drill or hydroseed, broadcast seeders can be used. When broadcast seeding, care should be taken to provide even coverage. This is usually achieved by seeding in perpendicular directions. Hand broadcasting is an acceptable method only in very small areas where mechanical seeders are inappropriate.

Sites should be mulched immediately after seeding. Mulches are used to conserve seedbed moisture during the germination and establishment period and to prevent erosion until seeded plants grow to a point where they can provide erosion control. Mulches should allow good air circulation while retaining moisture; should not be easily displaced by wind or water runoff; should be easy to apply and maintain; should be cost effective; and, should not persist longer than necessary.

On steep slopes vulnerable to erosion the best mulch materials are mats or erosion control blankets such as jute fiber mesh secured tightly to the soil surface. Straw mulches can be applied to shorter, flatter slopes or level ground. Straw should be applied at a rate of two tons/acre, and held in place by either crimping, use of tackifier, or netting staked to the ground. As suggested above, the best saw mulching technique is to use straw that is harvested along with the seed selected for planting.

11.15 Notice of Completion of Installation and As-Built Plans

After the installation all revegetation and irrigation materials is complete, an as-built drawing should be presented to the agency or contracting officer responsible for the project. A written notice of completion for the installation phase of the project. The date of inspection/approval of the as-built plans and installation phase for a project typically determines the beginning of the maintenance period.