CITY AND COUNTY OF SAN FRANCISCO
SEWER SYSTEM MASTER PLAN

TASK 500
TECHNICAL MEMORANDUM
NO. 502
DETAILED DRAINAGE PLAN MODELING APPROACH

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1.0 INTRODUCTION

The mission of the San Francisco Public Utilities Commission Wastewater Enterprise (SFPUC WWE) is to protect public health, public safety, and the environment by providing safe, reliable, and cost-effective and efficient collection, treatment, and disposal of wastewater and stormwater and control of combined sewer discharges. The SFPUC is solely responsible for the management, operation, and maintenance of the clean water utility, including all clean water/sewer-related assets owned or maintained by the City and County of San Francisco. SFPUC activities, operations, and functions are all geared to accomplish this mission. In meeting this mission, SFPUC is expected to provide maximum value relative to a “triple bottom line” of social, economic, and environmental standards.

The scope of the San Francisco Sewer System Master Plan Detailed Drainage Modeling Plan (DDMP) is to identify typical San Francisco drainage issues that, under certain conditions, may cause various types of flooding, to analyze alternatives, and to suggest improvements. The study is concentrated on seven focus areas within four of the city’s eight major drainage basins (Richmond, Channel, Islais Creek, Lake Merced). Figure 1 presents the eight major basins.

The DDMP is being conducted and delivered under the premise that flooding can cause risk to public safety as well as public health and that reasonable management and reduction of flooding occurrences will contribute to meeting the SFPUC mission. Furthermore it is to the economic benefit of the City of San Francisco to protect private property that generates economic vitality and tax revenues.

Figure 2 presents the seven focus areas and the extent of modeled pipes in the existing SSMP hydraulic compared to all pipes in the system. The seven areas represent typical drainage and flooding issues that can occur throughout the city and will be used to develop and compare different approaches to each issue. This process is intended to serve as a basis for future training of City staff and may be used as a template for future drainage analysis in the city.

The purpose of this document is to present the general modeling approach that is proposed to assess and analyze the drainage in the seven focus areas as well as evaluate alternatives for improvement. The modeling approach may include various techniques, methodologies, analyses, and data usage implemented to meet the goals of the project.
2.0 GENERAL MODELING APPROACH

The seven focus areas for the study have been selected with input from Bureau of Engineering (BOE) staff based on the potential and susceptibility to flooding issues. The types, causes, and degree of potential for flooding vary across the seven areas. The study will address the potential flooding issues, recommend mitigation criteria and alternatives, and provide insight for further future analyses.

The San Francisco Sewer System Master Plan (SSMP) model was developed using the InfoWorks software package to simulate dry-weather and wet-weather flows in pipes 30 inches and larger in diameter. It was developed primarily to predict the frequency and volume of combined sewer discharges to the ocean and San Francisco Bay. Figure 2 includes the extent of the sewer system represented by the SSMP model. Once calibrated, this tool was then used to analyze the impact of alternatives designed to reduce flooding and combined sewer discharge to the San Francisco Bay and the Pacific Ocean.
The current planning level model does not provide the level of detail necessary to conduct detailed drainage and flooding assessments. As such, it will need to be extended, refined, and updated to improve drainage and flooding analysis capability. The modifications will serve to better simulate existing conditions as well as the measures and alternatives that may be considered to improve the system. In general, three measures could be taken to enhance the model: (1) add additional network details (more pipes in upstream areas that are less than 30-inches in diameter), (2) add more detail to the hydrologic runoff simulation component, and (3) add a surface routing hydraulic component. One or more of these measures may be used according to the conditions and needs in each area. The model may also be further enhanced by taking advantage of more extensive or refined data that have become available since the development of the original SSMP model, including flow and rainfall monitoring and more refined physical data such as multi-spectral land use.
As part of the SSMP modeling, techniques for subcatchment delineation and model extensions were evaluated during a pilot study. They are summarized in a Draft Technical Memorandum dated March 21, 2007, entitled Subcatchment Delineation and Model Extent Process Memorandum. Some of these techniques and insights may be useful for this study. The pilot study focused on subdividing large subcatchments into smaller ones, adding previously unmodeled pipes, and validating nodes and pipes considered for inclusion.

2.1 Additional Network Resolution

The model can be refined for detailed drainage analysis by expanding the extent of the model to include more pipes and manholes, as well as other special structures. The current model generally contains pipes with a diameter of 30 inches or larger (with a few exceptions necessary to maintain continuity). This coarse level of detail is not sufficient to adequately address hydraulic issues in some areas (e.g. if there are issues associated with portions of the pipe system that are not represented in the model). A higher-resolution model of the City’s system may resolve these issues.

Before adding pipes upstream of the existing network, it is important to verify that the flow routing is detailed enough so that the new pipes will be appropriately loaded with flow. Incorrectly routing upstream runoff flows may cause flooding and hydraulic restrictions to falsely appear in model output or not appear when they should.

In some areas of the system, adding pipes without refining flow loading will be beneficial. For example, flooding in the South of Market Street (SoMa) area is mostly attributed to the subsidence of land. The lower land surface makes the area more susceptible to flooding due to the existing encroachment driven by the hydraulic grade line (HGL), which is influenced by upstream flows as well as downstream constraints. In this situation, adding smaller pipes without corresponding subcatchment and flow-loading refinement may be beneficial. The additional pipes will add storage to the system, which will be filled based on the HGL in the connected system. This will enhance the ability of the model to reproduce flooding in low-lying areas that formerly were not connected to the model pipe network.

2.2 Additional Hydrologic Detail

In instances where the addition of pipes requires the refinement of flow routing, subcatchment refinement may be required. This can be accomplished by subdividing the existing subcatchments and delineating smaller ones. These newly delineated subcatchments will then be routed to new flow-loading nodes, further upstream than the existing model extent. This measure, implemented in conjunction with network extension, will allow for better representation of how runoff and sanitary flows are directed to the sewer system and ensures the model network is an accurate representation of the collection system.
2.3 Surface Routing/Overland Flow Incorporation

In general, the measures described above will be sufficient to improve most of the model coverage areas. However, for some areas, the third measure may be required. InfoWorks, like many urban hydrologic and hydraulic models, is designed to simulate the hydrologic response to rainfall and produce a time-varying rainfall response hydrograph. This hydrograph is then assigned by the user to a corresponding node where it is (optionally) combined with base sanitary flow and becomes a flow input to the hydraulic network. The hydraulic engine then dynamically routes the flow through the system predicting HGL, flow, and velocity throughout the computational grid. This setup works well for all simulated periods when the HGL is below the top of manhole (rim) elevations. In instances where the HGL exceeds rim elevations, it is necessary to prescribe how the model should manage the floodwaters. In InfoWorks, when a node is flooded (having an HGL higher than the ground level), the program default is to store the excess water volume in a virtual cone above the nodes. When the HGL drops, the stored volume is rerouted through the node in the network. A user can override this default by either instructing that the manhole be sealed, which allows the HGL to rise above the rim elevation with no loss of water, or by allowing water to escape at that manhole location with little or no increase in HGL. While the default condition creates a simple representation of the system and aids in computation, it may not reflect reality, as water exiting a flooding manhole may not stay in the area around the flooded manhole. In most cases, the excess volume may pond or flow overland (via street or sidewalk) and re-enter the system further downstream, or if it cannot re-enter, it may continue flowing and cause flooding in other lower-lying parts of the city. These mechanisms can be simulated by the model.

The measures described above represent the three ways the model can be updated and refined to meet the ultimate project goal; that is, to simulate the storm response of the City’s system to an appropriate level of resolution, identify and analyze the potential causes of flooding, and finally, test and select alternative improvements for the focus areas. The model refinements can be implemented in selected areas or more globally throughout the entire model.

Implementation of these measures may require the use of additional data and more in-depth or extensive analysis. The following sections describe the analysis techniques and available data.

3.0 SUPPLEMENTAL DATA

One or more of the three measures described in Section 1 may be implemented for the focus areas of this study. This section describes supplemental data and analysis methodologies that may be used to extend and enhance the model for flooding analyses.
3.1 Multi-Spectral Land Use Data

The multi-spectral spatial data from National Climactic Data Center imaging for the city of San Francisco has been introduced into the GIS system in shapefile format. It provides detailed, up-to-date information for land use including asphalt, bare soil, grass, concrete, scrub, trees, etc., along with associated acreage. It can be used to improve the estimate of hydrologic parameter values in the InfoWorks model. Examples include improving the estimate of percent impervious versus pervious, Manning’s roughness coefficient (Manning’s N), and depression storage. Multi-spectral data also provides a good basis for further detailed Low Impact Design (LID) analysis as it enables a clear distinction between impervious surfaces such as roofs, driveways, streets, etc. This is useful when considering LID measures such as capturing roof runoff for water reuse, roof gardens, and street/driveway bioretention.

In the previously developed Master Plan model, a zoning map of San Francisco was used to estimate percent impervious versus pervious for land use. A percent impervious value was assigned to the subcatchments, calculated by taking the sum of weighed average for each. These values were then adjusted during model calibration. While this was sufficient for the SSMP analysis, it may not be detailed enough for the DDMP tasks. The multi-spectral data provides more accurate information since it contains each land type instead of rough zoning. The percent impervious can be estimated using the same method by assigning impervious value to each land type.

It is potentially time consuming to incorporate the data for the whole city and adjust the previous calibrated values. Therefore, for this project, multi-spectral data will be used selectively as appropriate for individual focus areas. If hydrologic parameters are adjusted using the multi-spectral data, the model results will need to be reviewed and checked against metered data. Based on model result comparisons to meter results, adjustment to other parameters may be necessary.

3.2 GIS/Database

The City maintains an Oracle database (also called GIS network) of its collection system. This database is often updated and corrected with new information about the sizes, shapes, and elevations of the various assets that it contains. This information originates from older as-built drawings (most of which are scanned and electronically stored) or from field surveys. The network of the SSMP model database was created using exports from this database. Details on this process and associated quality assurance/control measures can be found in the SSMP Baseline Report Technical Memorandum (Final Draft dated October 31, 2007).

Currently the GIS network model network and the SSMP do not have a one-to-one relation. Differences between the two databases can be attributed to the fact that the network in the model was further refined and updated during model construction to aid with calibration, and
the originating database was not updated. Most often, the differences are observed in shape, size, elevation, configuration, and the geometry. Differences in the geometry are mainly due to the addition of new nodes/links in the SSMP model database network for modeling purposes. There are also differences in the naming of otherwise identical objects. These inconsistencies can lead to conflicts when smaller pipes and other objects are added to the model, as will be described in Section 3b.

3.3 Flow Monitoring Data

The SSMP baseline model was calibrated using a set of 110 temporary flow monitors applied during the wet season of December 2004 through February 2005. An additional set of 32 flow meters were installed during the same time frame in the 2005/06 season. The SSMP baseline model calibration relied only on data from the first monitoring period. The second-period data may be used to improve confidence in the model through refining the existing model validation and fine tuning model performance in the seven focus areas. Global recalibration of the SSMP model is beyond the scope of this project. Figure 3 shows the location of flow meters for both monitoring phases. Table 1 lists the second-phase monitors and the percentage of time over the period that data were captured.

Data from the additional 32 flow meters have been reviewed in anticipation of using them to further validate the model. The review consisted of checking level-velocity scattergraphs. Pipes that are flowing freely under gravity will conform to a standard level/velocity relationship. Approximately 20% of the 32 additional meters demonstrate this standard relationship. There are a number of reasons that the relationship may stray from the normal pattern, including backwater or surcharging conditions at the meters and meter malfunction or failure. Second season data should be carefully reviewed for appropriateness prior to being used to enhance and refine the model.

The SSMP model previously developed and calibrated using phase 1 monitoring data was run for the phase 2 (second season) rainfall records to compare model results with phase 2 monitoring data; the results are tabulated in Appendix A. The comparison of the peak flows and depths for each of these flow meter locations provided a general guideline on the quality of the data and its usability for refining the model calibration of the existing baseline model for the DDMP purposes. These results should be closely reviewed prior to performing additional model validation.
Figure 3  Flow Meter Locations for the 2004/05 and 2005/06 Monitoring Periods
Table 1  Flow Monitoring Data Availability

<table>
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<th>FLOW METER PROGRAM - 12/06/05 TO 02/11/06 (68 DAYS)</th>
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4.0 ANALYSIS METHODOLOGY

4.1 Hydrology

Hydrology describes rainfall to runoff relationships in subcatchments and determines the hydrographic peakflow, timing, and volume of flow that each subcatchment contributes to the network via its loading node — it is a key component of the model. Hydrologic properties include the boundary of the subcatchment itself (which determines the contributing area), the percent pervious and impervious area, the percentage of pervious area that is directly connected to the hydraulic (pipe/manhole) network, the topography (slope), the infiltration
capacity, and the volume of detention storage (any surface storage that serves to detain and retain rainfall runoff). Included in the hydrologic module of the model is the input hyetograph(s) (rainfall increments per unit time over a specific duration). Also included in the hydrologic module is an estimation of non-rainfall flow components (dry-weather flows and groundwater infiltration).

During construction of the SSMP model, several subcatchment parameters were estimated including unit wastewater rate, population, baseflow due to infiltration, subcatchment width, slope, and percent impervious and pervious area. These values were estimated from city zoning maps. Later as part of the calibration process, the parameter values were further refined. Detailed description of the initial parameter estimation and the calibration can be found in the Baseline Report.

The results of the validation and a number of simulations performed for the SSMP suggest that the subcatchment parameters in areas where the calibration criteria were met have, in general, acceptable accuracy. Subcatchment parameters may be subject to inaccuracies for areas where the calibration criteria were not met.

Another assigned subcatchment property is the runoff routing model that is used by the model to calculate the response hydrograph of the subcatchment. InfoWorks provides users a number of options to simulate the rainfall-runoff process. One option is the US EPA Storm Water Management Model (SWMM) Runoff module. The SWMM method was selected for the SSMP model because it is widely used in North America and has been shown to perform well for urban settings. An alternative option is the Wallingford runoff method. The Wallingford method is potentially better suited to model the implementation of LID measures (for more details on LID, see in later sections). The application of LID measures, among other advantages, delays and flattens the peak flow coming from a subcatchment. In SWMM, the peak flow is governed predominantly by the basin width and slope, which are unique for each subcatchment. In order to implement LID using the SWMM runoff method, a new subcatchment for every LID measure is necessary. This can lead to multiple superimposed subcatchments draining to the same node.

In the Wallingford method, the runoff is controlled by coefficients that correspond to various runoff surfaces. A subcatchment can have numerous coefficients. Therefore, with the use of the Wallingford method, there can be multiple runoff surfaces representing LID in the same subcatchment, and they can all have different routing coefficients. This method may therefore be more suitable for LID modeling.

To switch from the SWMM runoff method to the Wallingford runoff method, a verification of the model would be required (and possibly additional calibration), since the two methods use different subcatchment parameters.

The user should consider advantages and disadvantages of both methods prior to selecting one over the other. Advantages relate to efficiencies in modeling LID measures and
maintaining consistency with the existing SSMP model and methodologies. The disadvantages relate to the effort to setup and implement the revised method and the requisite validation and possible additional calibration/verification. However, additional calibration may be needed regardless of the runoff method change. It should be noted that the choice of runoff method does not have to be global; different runoff methods can be used in different subcatchments. The choice of the hydrology method for the model in each of the seven focus areas will be made specific to the conditions in each basin as well as the types of alternatives and improvements that may be considered in each area.

Selection of a rainfall hyetograph input to the model is usually associated with the hydrology module. The city’s sewers were designed to offer flood protection for a storm with a 5-year return period. The so-called 1941 storm is often used to represent the 5-year recurrence storm. It is a synthetic rainfall of 3-hour duration. It is important to emphasize storms of a given recurrence interval such as 5-year (once in 5 years or 20% probability in any given year) must be associated with specific durations. The same recurrence over different durations may yield different results as the associated total volume and intensity of rainfall will be different. SSMP Project Memorandum (PM) 2A Rainfall Analysis Technical Memorandum summarizes a comprehensive rainfall analysis to evaluate and recommend design rainfall. The 5-year, 3-hour storm will be used to consider Drainage Plan focus area improvements. Larger storms may also be used in order to document conditions more severe than design conditions.

4.2 Pipe Network

The SSMP model included pipes with 30-inch diameter (or equivalent, if not circular) and larger. Some smaller sewers, essential to the continuity of the system model, were also included. Larger sewers were excluded from the model when they were either plugged or carried no significant flow.

As discussed above, a measure to enhance the model’s capability to analyze focus areas is the introduction of smaller pipes in the model network. There are two ways that this can be done – either strictly locally and only within the focus areas, leaving the rest of the network as is or by adding more pipes in a large part of the system and adding even smaller pipes within the focus areas. For the second case this could mean that pipes small as 18 inches in diameter will be added in the major basins that contain one or more focus areas and within the focus areas, wherever needed, even smaller pipes will be added according to each area’s specific issues and characteristics.

Adding new pipes may create data conflicts in the model network, such as duplicate objects and missing connections of new objects to the older network due to the inconsistencies mentioned in the previous section. There are two ways to resolve these conflicts.

The first is to use an updated Oracle database that will have a one-to-one relation with the SSMP network. This could be achieved either by (1) removing from the GIS network the
objects that are common but different from the SSMP network or (2) adding to the GIS these different objects and creating duplicate objects. The use of a field denoting in which network each object is used would resolve the problem of having duplicate objects. Such an update of the Oracle database is beyond this project’s scope.

The second way to resolve data conflicts in the model network is to add the new objects and then manually and visually resolve any conflicts. Such a manual procedure was used during the SSMP modeling. In order to enhance the visualization of flooding during the simulations, some additional local pipes were added in a few parts of the network. Pipe addition for the seven focus areas will also involve a manual approach.

There are two approaches for refining the model for specific focus areas. One is to create a sub-basin model for each of the drainage basins and apply boundary conditions; the second is to simulate the system wide model. The sub-basin models are suitable for areas that are at the upstream parts of the city. The sub-model of an area will be created by selecting the respective part of the existing SSMP Baseline Network and creating a new local network with the selected objects. The model refinements will be implemented to the local network. To simulate the model’s response to rainfall, boundary conditions must be added. The furthest downstream node of the sub-model can be replaced with an outfall node. The outfall node has a field in which the water level can be pre-specified. Usually that level corresponds to the sea tide level. However, one can run a simulation of the whole network, record the level at that node, and then use it as a boundary condition. It must be noted that the changes to the local network will affect the area’s response, which may result in a different water level at the furthest downstream node. The use of an outfall, however, will not allow the local network to reflect such a change. Therefore, the local network solutions must be iterated and checked for convergence.

By creating sub-basin models, a large length of simulation time can be truncated. Instead of running the whole network, one can use the sub-models to simulate each area’s improvement alternatives. The disadvantage is that the sewer system of San Francisco is very complex with many interconnections and interactions the local networks cannot simulate. For instance, the boundary conditions of one local area may change due to flooding mitigation measures implemented in other neighboring areas. Finally, there may be flooding that occurs in the downstream part of the city, where the many boundary conditions interact (many inputs from upstream areas and many downstream controls such as overflow weirs, Transport/Storage facilities, etc.). In this case, a local network approach may not be suitable.

The disadvantages of the sub-model method point to the adoption of a global, citywide modeling method. It must be noted that although the sub-models require less simulation time, the difference may be insignificant, due to the fact that the simulation periods will be a few dozen hours (i.e., 24 or 36 hours). These periods are simulated in about 15 minutes or maybe less if a server is used. Therefore the basic advantage of the sub-models method is questionable. An obvious advantage of the global method is that there will be only one
network, instead of many local networks, making network comparisons, copies, transfers, and file management much easier. This may prove very crucial, since the InfoWorks file managing system is cumbersome.

The global network method can be implemented by either expanding the network extent for each flooding area of interest or by expanding it in all the flooding areas. The first will result in many citywide networks with expanded extents; the second will result in one network that contains all the new objects. The two ways could also be combined. In a preliminary phase one can use the first way to make an initial assessment of the various mitigation alternatives’ benefits and then use the second way to find the impacts of the combination of the local solutions to the whole network along with their interactions.

4.3 Surface Routing

To model the overland flow, open channels must be added to simulate the surface routing of volume to downstream nodes. Figure 4 depicts the network of surface conveyance (for example, trapezoidal channels) facilities that would need to be developed in the model to enable surface routing as compared to the model default mode in which water is stored above the surface until the HGL drops adequately to move the stored water through the primary conveyance pipe system.

To facilitate this, a Digital Terrain Model of the street network can be used to identify and facilitate the setup of the model overland flow paths. In addition, there are custom routines available within InfoWorks that automatically create the overland flow paths. The custom routines automate the process of adding channel segments along the surface to connect successive nodes. A recently available add-on module to the base InfoWorks software enables the user to route water on the surface according to the detailed topography. While this capability would be useful for this study, the data resolution requirements and cost of software may preclude its use.
4.4 Low Impact Design (LID)

The LID practices that will be implemented by the City of San Francisco may have the effect of reducing or detaining peak flows and volumes as well as desynchronizing stormwater flows into the sewer system. According to the previous research study accomplished by Carollo Engineers, the LID practices that may be most applicable for the city are: ecoroofs, street trees, roof-drain disconnection, bioretention systems, and permeable pavement systems.

Carollo Engineers have made suggestions for model simulation parameters for different LID practices, excerpted into Table 2.

The DDMP will help identify areas that may have the potential for flooding and the basis. Block scaled models of LID implementation can be developed for those flooding areas to identify how the LID practice can mitigate localized flooding. For example, an individual subcatchment with flooding problems can be modeled with or without LID and results (hydrograph peak flow, timing, and volume; and frequency and extent of flooding) compared. Moreover, increased infiltration can be introduced into the model for bioretention and permeable pavement practices.
### Table 2: Model Representations for Each LID Practice

<table>
<thead>
<tr>
<th>BMP</th>
<th>Expected Performance</th>
<th>Model Representation</th>
<th>Model Parameters</th>
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</thead>
<tbody>
<tr>
<td><strong>Ecoroofs</strong></td>
<td>• Absorb the first 0.4 to 0.8 inches of rainfall&lt;br&gt;• Reduce runoff volume&lt;br&gt;• Delay the onset of runoff&lt;br&gt;• Reduce peak runoff rate</td>
<td>• Impervious surface type with elevated depression storage and roughness&lt;br&gt;• A portion of impervious surface is converted to ecoroof surface</td>
<td>• Depression storage 0.4 - 0.8 in&lt;br&gt;• Manning’s N 0.6 - .15&lt;br&gt;• No infiltration</td>
</tr>
<tr>
<td><strong>Street Trees</strong></td>
<td>• Intercept a portion of the rainfall, depending on tree size&lt;br&gt;• Reduce runoff volume</td>
<td>• Impervious surface type with elevated depression storage and roughness&lt;br&gt;• Total crown area converted from impervious area to street tree area&lt;br&gt;• Area converted is equal to the total crown area&lt;br&gt;• Depression storage equal to maximum interception rate for a single storm</td>
<td>• Depression storage 0.14 - .07 in&lt;br&gt;• Manning’s N 0.2 - .6&lt;br&gt;• No infiltration</td>
</tr>
<tr>
<td><strong>Roof-Drain Disconnection</strong></td>
<td>• Reduce runoff volume&lt;br&gt;• Reduce runoff peak</td>
<td>• Assumed to be removed from the contributing area and contained in Cisterns or routed to infiltration.</td>
<td>• Subcatchment area reduced by roof disconnect area</td>
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<tr>
<td><strong>Bioretention</strong></td>
<td>• Delay the onset of runoff&lt;br&gt;• Reduce peak runoff rate</td>
<td>• One detention storage unit within each subcatchment, sized to detain the runoff from the drainage area within that subcatchment&lt;br&gt;• Drainage orifice sized to drain storage volume within 72 hours&lt;br&gt;• Overflows into sewer network</td>
<td>• Storage volume = drainage area design storm depth&lt;br&gt;• Design storm depth = 0.5 in</td>
</tr>
<tr>
<td><strong>Permeable Pavement</strong></td>
<td>• Delay the onset of runoff&lt;br&gt;• Reduce peak runoff rate</td>
<td>One detention storage unit within each subcatchment, sized to detain the runoff from the drainage area within that subcatchment&lt;br&gt;• Drainage orifice sized to drain storage volume within 72 hours&lt;br&gt;• Overflows into sewer network</td>
<td>• Storage volume = drainage area storage depth&lt;br&gt;• Storage depth = 8 in</td>
</tr>
</tbody>
</table>
4.5 Typical Drainage/Flooding Issues

The potential for flooding in San Francisco is generally related to one or some combination of six conditions. They are briefly discussed below.

A. Extreme rainfall events. Extreme rainfall events resulting in runoff that exceeds the design capacity of the drainage system may cause flooding. The runoff may exceed the capacity of either the catchbasin inlets and/or the sewer conveyance facilities. When extreme event flooding occurs, the goal is to ensure that the flooding does not cause loss of life or extreme property damage. In general, when the drainage system capacity is exceeded, the worst consequence should be minor surface ponding and street flooding.

B. Increased flows resulting from increased imperviousness in upstream tributary areas associated with development and/or redevelopment. These increased flows and velocities in turn impact downstream facilities. Remedies to this problem may include code changes, controlling the increased runoff with best management practices and/or LID to reduce flow, replacing older sewers with new larger-capacity sewers to reflect current land use and development, and lowering of the friction factor in major concrete trunk sewers to increase capacity.

C. Pipe slope transition. San Francisco’s topography is extremely hilly. There are many locations where steep pipes abruptly connect with milder slope pipes. These situations can result in hydraulic jumps which may cause the hydraulic grade to exceed ground elevation.

D. Downstream hydraulic grade line restrictions. Some areas of the City experience higher HGL levels within the sewers due to water levels at the downstream control points, such as the transport storage boxes and weirs. Because most trunk sewers and all transport storage boxes and outfalls weirs are located in the low-lying areas, flows from local sewers that are interconnected with these trunk sewers and transport structures cannot enter into them because of the amount of flows taken in by earlier collected upstream flows. When this occurs, local low-lying area flows will back up, causing flooding on the surface until the flows within the trunk sewers and transport box structures recede. Remedies for this problem may include optimizing a combination of (a) reducing flow into the system, (b) increasing storage, treatment, and pumping, (c) providing backflow prevention devices within private properties, and (d) informing owners when new developments are within areas of HGL restrictions.

E. Subsidence of land. Some areas in San Francisco were once open marshlands and part of the Bay tidal zone. China Basin, Bayview/Hunter’s Point, and Embarcadero, for instance, are areas created by fill. Main sewers built to collect the flows in these areas were usually built on piles. Soil materials used for Bay fill are still consolidating, resulting in surface settling. Because the main sewers were built on piles, they remain at their
original elevation along with the roadway crown, but beyond the sewer-on-pile zone, the surrounding land, roadway, sidewalks, and buildings have settled in some cases lower than the crown of the road. Hydraulic studies have shown that within subsidence areas of San Francisco, the sewer systems’ hydraulic grade line during storms is higher than current street and sidewalk elevations. Remedies to this issue are challenged by property ownership. The City has the jurisdiction to raise the subsided land in the public right-of-way but not directly on private land. Flooding on private land subsidence areas may be exacerbated should adjacent public lands be filled and raised. Private land modification must be conducted in cooperation with the owner or developer.

F. Reduced cross-sectional area and capacity of sewers. The initial runoff from major storm events often carries debris into catch basins. This blockage can potentially impede storm flow conveyance within the system. Larger-size debris not ultimately carried to the treatment facilities, as well as finer grit that can build up within the sewer, reduces sewer system capacity, creating unnecessary restrictions. Partially deteriorated pipe crowns that require repair or replacement also reduce pipe conveyance capacity. Depending on the intensity of a storm when it hits in the city, sewer backups can occur and cause flooding into the streets and adjacent properties because of compromised conveyance capacity within the system.

Figure 5 provides a graphical representation of the potential problems discussed above.

In areas where the cause of flooding is downstream hydraulic grade line restrictions or subsidence, the first measure of the modeling approach, described in Section 1, may be sufficient. In other areas however, where flooding is caused by the other described issues, it may be necessary to use the second and maybe the third measures described in Section 1.
Figure 5a  Flooding caused by extreme rainfall event

Figure 5b  Flooding caused by increased upstream imperviousness

Figure 5c  Flooding caused by pipe slope transition (hydraulic jump)
Figure 5d  Flooding caused by downstream conditions

Figure 5e  Flooding caused by street subsidence

Figure 5f  Flooding caused by debris and/or corrosion and deterioration of pipes
4.6 Additional Model Calibration

For the DDMP modeling of the focus areas, additional model validation enhancement may be performed using the additional phase 2 flow-monitoring data. Various modeling approaches have been described for the general purpose of improving the ability of the model to analyze drainage issues in the seven focus areas. Certain areas may require greater model refinement and extension than others. Model changes may be significant enough to render the previous SSMP model validation inadequate. The general methodology for enhancing the model, including incorporating new data into the validation, is listed below. These generalized methods may be customized according to the conditions and needs in each area.

A. Review existing model calibration. The first step is to review the existing (phase 1) model calibration for both the dry-weather flow days and the wet-weather events. This information will provide a quantitative and qualitative assessment on the model flows and basis for further improvement.

B. Introduce/incorporate new model elements. The introduction of the new model elements along with the accuracy of the existing calibration will govern the need and effort in improving the calibration. When additional hydraulic elements are added to the model, the corresponding subcatchments will need further delineation to accommodate the new pipes and manholes. The delineated subcatchments will be assigned newer loading points and new dry-weather flow allocations.

C. Review flow meter data. The phase 2 flow meter data will be reviewed and certain wet-weather events will be selected for the model validation enhancement. The calibration criteria will remain the same as that imposed during validation of the SSMP baseline model. Care must be taken to use a model representation of the system that replicates as closely as possible the system as it was during the period over which monitoring data were obtained.
4.7 Model Validation Refinement Process

The model may be further refined and adjusted to accommodate specific analysis of the seven focus areas. The level of efforts in each area will be determined by the specific issues in each area and the status of current calibration.

For most of the focus areas, system performance is highly correlated to downstream boundary conditions (tide level; water level in the storage/transport boxes). Most areas are well represented by the flow-monitoring program and well suited for model refinement. The model enhancement will include most pipes above the size threshold of 18- or 24-inch diameter. Subcatchments will be refined to correlate to the additional pipe representation. Downstream conditions will be re-evaluated and the model refined to reduce the potential for instabilities that may result from the increased complexity attained through model refinement.
Appendix A presents flow monitoring data for the second season flow meters. The plots show level, velocity and flow as well as the level-velocity scatter graph during the temporary flow monitoring period of December 2004 through February 2005. Figure 1 shows the location of the phase 1 and phase 2 flow meters.

Figure 1 December 2004-February 2005 (Phase 1) and December 2005-February 2006 (Phase 2) Flow Meter Locations
APPENDIX A
Meter Name: SF_E24

![Graph 1: Level (inches) vs. Velocity (feet/sec)]

![Graph 2: Flow (MGD) vs. Date]

![Graph 3: Velocity (feet/sec) vs. Level (inches)]
**Meter Name: SF_W06**

1. **Level (inches) vs. Velocity (feet/sec)**
   - X-axis: Dates from 12/6/05 to 2/7/06
   - Y-axis: Level in inches (0 to 45) and Velocity in feet/sec (0 to 20)

2. **Flow (MGD)**
   - X-axis: Dates from 12/6/05 to 2/7/06
   - Y-axis: Flow in MGD (0 to 120)

3. **Level (inches) vs. Velocity (feet/sec)**
   - X-axis: Level in inches (0 to 45)
   - Y-axis: Velocity in feet/sec (0 to 20)
APPENDIX B - COMPARISON OF DEPTH AND FLOW OF THE BASELINE MODEL TO SECOND SEASON FLOW METERS
Appendix B compares the depth and flows of the baseline calibrated model with the second season (Phase 2) flow meters. The comparisons are presented for three significant events that occurred during the Phase 2 flow monitoring program. Rainfall data from gauges in three basins were used, RG 16 for Ingleside basin, RG 24 and 25 for Cayuga basin and RG 30 for Channel basin. Table 1 shows the rainfall characteristics for the events that were selected.

Table 1. Rainfall Characteristics for Second Season Flow Monitor Comparison to Model Results

<table>
<thead>
<tr>
<th>Rain Gage</th>
<th>Event 1</th>
<th>Event 2</th>
<th>Event 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duration (hrs)</td>
<td>Peak Intensity (in/hr)</td>
<td>Depth (in)</td>
</tr>
<tr>
<td>RG 13</td>
<td>6.4</td>
<td>0.96</td>
<td>1.1</td>
</tr>
<tr>
<td>RG 16</td>
<td>6.1</td>
<td>0.84</td>
<td>0.85</td>
</tr>
<tr>
<td>RG 24</td>
<td>4.7</td>
<td>0.72</td>
<td>0.7</td>
</tr>
<tr>
<td>RG 25</td>
<td>3.9</td>
<td>0.48</td>
<td>0.54</td>
</tr>
<tr>
<td>RG 30</td>
<td>3.3</td>
<td>0.48</td>
<td>0.5</td>
</tr>
</tbody>
</table>
APPENDIX B
Meter ID: SF_W1

**Event 1: 12 - 22**

**Event 2: 12 - 30**

**Event 2: 2 - 01**

**Depth (feet)**

**Flow (MGD)**

**Modeled**

**Observed**
Meter ID: SF_W5

Event 1: 12 - 22

Event 2: 12 - 30

Event 2: 2 - 01

Depth (feet)

Flow (MGD)

Modeled

Observed

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5

0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00

0 50 100 150 200 250 300

0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8

0.00 0.00 0.00 0.00 0.00 0.00 0.00

0.00 0.00 0.00 0.00 0.00
Meter ID: SF_E27

Event 1: 12 - 22
Meter ID: SF_E27

Event 2: 12 - 30
Meter ID: SF_E27

Event 2: 2 - 01
Meter ID: SF_E27

Depth (feet)

Flow (MGD)

Modeled
Observed

Depth (feet)

Modeled
Observed

Depth (feet)

Modeled
Observed

Depth (feet)

Modeled
Observed

Flow (MGD)

Modeled
Observed

Flow (MGD)

Modeled
Observed

Flow (MGD)

Modeled
Observed

Flow (MGD)
Meter ID: SF_E1

Event 1: 12 - 22
Meter ID: SF_E1

Event 2: 12 - 30
Meter ID: SF_E1

Event 2: 2 - 01
Meter ID: SF_E1

Depth (feet)

Modeled

Observed

Flow (MGD)

Modeled

Observed
Meter ID: SF_E02

Event 1: 12-22
Meter ID: SF_E2

Event 2: 12-30
Meter ID: SF_E2

Event 2: 2-01
Meter ID: SF_E2
Meter ID: SF_E04

Event 1: 12-22
Meter ID: SF_E4

Event 2: 12-30
Meter ID: SF_E4

Event 2: 2-01
Meter ID: SF_E4

Depth (feet)
Modeled
Observed

Flow (MGD)
Modeled
Observed
Meter ID: SF_E09

Event 1: 12 - 22
Meter ID: SF_E9

Event 2: 12 - 30
Meter ID: SF_E9

Event 2: 2 - 01
Meter ID: SF_E9

Depth (feet)

Modeled
Observed

Flow (MGD)

Modeled
Observed
Meter ID: SF_E18

Event 1: 12 - 22

Event 2: 12 - 30

Event 2: 2 - 01