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Northern and Central California, Nevada, and Utah
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Prepared for

DEPARTMENT OF THE NAVY
Naval Facilities Engineering Command
Southwest Division
San Diego, California

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F HUNTERS POINT SHIPYARD SAN FRANCISCO, CALIFORNIA

April 22, 2002

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April 22, 2002

Keith Forman
BRAC Environmental Coordinator
Department of the Navy
Naval Facilities Engineering Command, Southwest Division
1230 Columbia Street, Suite 1100
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Dear Mr. Forman:

Please find attached our Technical Correspondence, *Evaluation of Storm Water and Solids Delivery to Parcel F*, provided to you for your use. The so-called "soil-to-bay" pathway was identified by the BCT as a concern for potential contaminant contribution to Parcel F. In response to this concern, TtEMI conducted modeling as described in this document, to estimate the potential surface water flow and erosion to transport solids to Parcel F via storm drains and surface runoff.

The findings of this study, which will be referenced in several future projects, provides a basis for a more focused look at key areas of the shipyard that may have connection with sediment areas of concern. We look forward to working with the Navy RPM team to integrate source area concerns with future remedial efforts offshore.

Sincerely,

Douglas Davenport
Tetra Tech EM Inc. Project Manager

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ABBREVIATIONS AND ACRONYMS

DEM	Digital Elevation Model
FSWEPP	Forest Service Water Erosion Prediction Project
GIS	Geographic Information System
HPS	Hunters Point Shipyard
msl	Mean sea level
tons/acre-year	Tons per acre per year
Ogden	Ogden Beeman & Associates, Inc.
TtEMI	Tetra Tech EM Inc.
WEPP	Water Erosion Prediction Project
YEI	YEI Engineers, Inc.

1.0 INTRODUCTION

To evaluate potential contaminant transport from Hunters Point Shipyard (HPS) to the San Francisco Bay (hereafter referred to as Parcel F), it is important to estimate surface water flow and erosion potential at HPS. The extent of erosion and solids yield from HPS relates to a complex interaction between topography, soil type, climate, vegetation, land use, and manmade developments. This document presents the results of a preliminary evaluation of peak flows and solids yields from HPS to Parcel F.

The report is organized as follows. Section 1.0 summarizes the evaluation purpose and HPS background. Section 2.0 describes conceptual model of material transport at HPS. Section 3.0 presents the approach to evaluate storm water and solids delivery from HPS to Parcel F. Section 4.0 describes the methodology and models used. Section 5.0 discusses the results, and Section 6.0 summarizes the findings. Section 7.0 presents the references used to prepare this report, and figures and tables follow Section 7.0.

1.1 PURPOSE

The purpose of the evaluation was to determine whether overland erosion from HPS is a significant contributor of solids to Parcel F. This document presents the approach and methodology used to calculate yearly erosion rates and discusses evaluation results. The Navy will use the results of this evaluation to help determine the potential for contaminated soil to be transported from HPS to Parcel F through soil erosion. An understanding of flow pathways, erosion potential, and generated kinetic energy of the area is an essential component of the contaminant transport evaluation.

1.2 BACKGROUND

HPS is located on a promontory in the southeastern corner of San Francisco, extending eastward into the Bay. HPS is bounded on the north and east by the Bay and on the south and west by the Bayview/Hunters Point district of San Francisco (Figure 1). HPS consists of approximately 493 dry land acres (Parcels A through E) and 443 underwater acres in Parcel F.

Between 70 and 80 percent of HPS land consists of relatively level lowlands that were constructed by excavating portions of surrounding hills and placing nonengineered fill material along the margin of San Francisco Bay. Therefore, about 400 acres of the dry land portion of HPS is a level plane from 12 to 15 feet above mean sea level (msl). The remaining land, which is composed mostly of Parcel A (Figure 2), is a moderate to steep, sloping northwest-trending ridge. Figure 3 shows ground surface elevation contour lines for HPS. The maximum elevation at HPS is approximately 180 feet above msl (Figure 3).

Surface water at HPS drains primarily in a sheet-flow pattern from either the highlands of Parcel A to the surrounding lowlands or from the lowlands themselves. In about 90 percent of HPS, the storm drain system collects runoff, which discharges to San Francisco Bay through outfalls. The existing storm sewer system was developed in sections and functions as 10 independent drainage systems (YEI Engineers, Inc. [YEI] 1988). For the purpose of this evaluation, the Navy refers to these systems as "catchments" C1 through C10. Approximately 10 percent of the HPS surface, including undeveloped shoreline, some pier areas, and parking lots, is not underlain by the storm drain system. HPS catchments that are not underlain by storm sewers were designated as catchments C11 and C12, respectively. No naturally occurring channelized drainage remains at HPS. Preexisting drainage channels were filled in or modified by construction over the years. Figure 4 shows the location and distribution of the storm drain and sanitary sewer lines at HPS.

HPS is underlain by both unconsolidated deposits and bedrock. Unconsolidated deposits of sand, gravel, and clay overlie the Franciscan Assemblage Bedrock throughout most of HPS. Surface soil is composed of mostly fill materials, consisting of silts and sands with varying amounts of gravel (Tetra Tech EM Inc. [TtEMI] 1998).

Cool summers with little precipitation and mild winters with moderate precipitation characterize the climate in the HPS area. Normal annual rainfall in San Francisco, as monitored at the San Francisco Federal Building, is approximately 20 inches (TtEMI 1998). However, this amount can vary significantly, especially during El Niño years (which occur with every 3- to 4-year) when rainfall can increase to 150 percent or above normal rainfall. Prevailing wind direction is west to east toward Parcel F, with the average and maximum wind speeds at HPS of approximately 15 and 30 feet per second (TtEMI 1998).

2.0 CONCEPTUAL MODEL OF MATERIAL TRANSPORT

Erosion and deposition result from rainfall and runoff and vary significantly from year to year, depending on frequency and magnitude of rainfall. Figure 2 presents a conceptual model of solids transport processes at HPS.

Erosion depends on soil type, landform, and land cover (such as vegetation and pavement). HPS is composed of erosional and depositional land surfaces. Erosional surfaces are a source of solids, and depositional surfaces retain solids on HPS before it can be delivered to Parcel F. Therefore, the amount of solids delivered to the Bay is less than the amount of all eroded materials produced on HPS. Erosion is

the dominant geomorphic process on areas that are convex, and depositional is the dominant geomorphic process in areas that are concave (Hadley and Toy 1977).

Approximately 58 percent of HPS dry land surface is paved; however, the pavement is old and often broken. The remaining 42 percent of HPS dry land surface consists of bare or vegetated areas (mostly tall grasses and bushes). Paved surfaces are not source areas for soil erosion; however, solid materials may be imported from unpaved HPS areas and deposited on the pavement surface. As a result, paved surfaces may temporarily store materials from upland areas or from atmospheric deposition, later becoming sources of these materials. Subsequently, these solid materials may erode from the paved areas and travel to Parcel F.

3.0 APPROACH

TtEMI used the following assumptions to ensure conservative predictions of erosion and to develop sedimentation and a worst-case assessment of solids delivery from HPS to Parcel F:

1. All solids delivered to the storm sewer system are delivered to Parcel F, and all discharge from catchments C1 through C10 is through storm sewers to Parcel F.

2. All suspended solids are potentially transported by overland flow to the shore of catchments C11 and C12 and into Parcel F.

The Navy used the steps below to formulate conclusions on the potential for solids delivery from HPS to Parcel F.

Step 1: Evaluate the potential delivery of kinetic energy from HPS through existing storm drains and overland flow to Parcel F.

Step 2: Identify and quantify areas subject to soil erosion and deposition based on geomorphology (in particular, slope and curvature).

Step 3: Estimate potential erosion at HPS using a physically based model.

Step 4: Compare predicted erosion from catchments against accretion in Parcel F.

Section 4.0 discusses each of these steps separately.

4.0 METHODOLOGY

Sections 4.1 through 4.4 discuss Steps 1 through 4, respectively. These steps were used to evaluate the potential for solids delivery from HPS to Parcel F.

4.1 EVALUATE WATER AND ENERGY DELIVERY FROM HPS TO PARCEL F

Material and energy is delivered from HPS to Parcel F by surface water runoff, groundwater flow, and storm water runoff. Surface water runoff by overland flow is expected to be limited. Although groundwater transport and surface flow adds volume to Parcel F, kinetic energy associated with these means of transport is not sufficient to redistribute subtidal sediment. Therefore, this evaluation focuses predominantly on kinetic energy attributed to storm drain flow and associated solids delivery. The delivery mechanism is somewhat uncertain due to (1) tidal influence on the storm drains, (2) gradient reversals in some sections of the storm drains because of subsidence, and (3) the storm drains' ability to handle 5-year design flows (Appendix B; YEI 1988).

TtEMI evaluated a previous storm sewer investigation at HPS (YEI 1988) and past infrastructure reports and diagrams on the storm sewer system. During their investigation, YEI concluded that the storm sewers drain most of HPS, and surface runoff is possible in areas not underlain by the sewer system (YEI 1988). Each system has its own tributary drainage area and an outfall at Parcel F. Figure 4 shows the outfalls at HPS. YEI also evaluated the storm sewers' ability to accommodate 2-year and 5-year storm events. YEI concluded, and TtEMI verified, that the existing system is capable of handling a 2-year storm event, whereas only portions of the system are capable of handling discharge from a 5-year storm event. Appendix B presents the results of the storm water system verification.

Based on a topographic elevation map with a 1-foot contour interval (Figure 3), TtEMI developed geographic information system (GIS)-based Digital Elevation Model (DEM) to digitally generate a flow direction grid, potential watercourses, the boundaries of HPS lands that contribute to the watercourses, and stream networks at HPS and the surrounding area based on topography (Appendix A). For catchments C11 and C12, which are not drained by storm sewer system, the GIS modeling process identified "pour points," where each catchment hypothetically discharges to Parcel F (Figure 4). Figure 4 also shows storm sewer outfalls for catchments C1 through C10.

TtEMI inspected the pour points and other areas along the HPS-Parcel F interface in July 2001 to investigate the possible presence of surface expressions indicative of surface water runoff (primarily for catchments C11 and C12). During the inspection, TtEMI observed a gully in a portion of catchment C12. The gully flows into a bermed area, and the only outlet to the Bay is through an elevated pipe. Water appeared ponded within the berm and was very clear. If sediment is transported down the gully, it is likely filtered by vegetation and settles rapidly. Little to no transport of solids is expected to occur through this gully.

4.2 IDENTIFY AND QUANTIFY AREAS SUBJECT TO EROSION OR DEPOSITION

The slope of the land surface, slope curvature, and land cover are the dominant factors that affect erosion. TtEMI quantified these factors using the DEM model and GIS land-use coverages available for HPS. TtEMI used the resulting estimates of slope, slope length, and percentages of land cover types as inputs to the physically based models (Section 4.3).

The eroding force per unit area is directly proportional to the slope of the land surface (Leopold and others 1964; Horton 1945). Generally, steeper slopes have a higher erosion risk than gentle slopes. TtEMI used the DEM to determine the distribution of slopes by steepness for HPS, as shown on Figure 5.

TtEMI analyzed landform curvature using GIS to identify zones with dominant erosional or depositional geomorphic processes. Erosion is the dominant geomorphic process on slopes that are convex (or have a positive curvature). Deposition is the dominant geomorphic process on slopes that are concave (or have a negative curvature) (Hadley and Toy 1977), as shown on Figure 6. TtEMI identified locations at HPS where sediment is retained as depositional surfaces. Figure 7 presents data on the percentage of HPS that is relatively flat and depositional and relatively steep and erosional.

Figure 8 shows land cover types, including paved and unpaved areas and areas covered by trees or shrubs. Figure 9 presents flow lengths to the storm drain inlets. TtEMI used flow length, slope steepness, land cover type, and other parameters as input parameters for the physically based model. Section 5.0 further discusses areas that are subject to erosion and deposition.

4.3 ESTIMATE POTENTIAL EROSION USING A PHYSICALLY BASED MODEL

TtEMI applied the U.S. Department of Agriculture Forest Service's Internet-based Forest Service Water Erosion Prediction Project (FSWEPP) model (Elliot and others 2000) to each of 12 catchments to develop a conservative prediction of potential erosion at HPS. In addition, TtEMI compared the predicted erosion from two subcatchments within catchment C1 with sediment accretion at Parcel F, as described in Section 4.4.

The FSWEPP model is a simplified version of the Agricultural Research Service's Water Erosion Prediction Project (WEPP) computer program. FSWEPP can be modified for use as a physically based soil erosion model to approximate a wide range of conditions, including those at HPS. However, the model cannot be used for urban environments. Any predicted runoff or erosion value using any model will be within only plus or minus 50 percent of the true value. Since erosion rates are highly variable,

most models can predict only a single value, and replicated research has shown that observed values vary widely for identical plots or for the same plot from year to year (Elliot 1999; Elliot and others 1999). In addition, spatial variability of soil properties adds to the complexity of erosion prediction (Robichaud 1996).

Based on consultation with Elliot (TtEMI 2001), TtEMI considers FSWEPP to be suitable for an initial evaluation of potential erosion at HPS. Appendix C describes the FSWEPP model and modeling assumptions. Section 5.0 presents the modeling results.

4.4 COMPARE PREDICTED EROSION FROM CATCHMENTS AGAINST SEDIMENT ACCRETION IN PARCEL F

Sediment accretion rates at HPS have been documented in a number of studies by the U.S. Army Corps of Engineers (Ogden Beeman & Associates [Ogden] 1992). These studies provide the sedimentation rate and estimates for sediment accretion along the shoreline. The most aggressive accretion rate occurs along the southeastern face of the HPS in the pier areas. These areas accumulate up to 0.25 foot of sediment per year. These rates are supported by dredging records showing the need for constant dredging to maintain access for ship traffic at HPS.

TtEMI delineated two subcatchments (C1A and C1B) to compare predicted erosion from HPS catchments with sediment accretion in the pier areas (Figure 4). Subcatchments C1A and C1B are in catchment C1. TtEMI assumed that solids delivery from subcatchments C1A and C1B was along Berths 29 and 23, respectively. Solids delivery is through both overland flow and storm sewers. TtEMI used the FSWEPP model to estimate potential erosion from these subcatchments (Appendix C).

For comparison purposes, the pier areas where accretion occurs were set equal in size to the subcatchment areas. In addition, TtEMI considered a suitable range of sediment bulk density when converting predicted annual erosion rates for subcatchments (kilograms per square meter) to the published accretion rate (feet per year). Section 5.0 presents the results of predicted erosion from subcatchments C1A and C1B.

5.0 RESULTS

The sections below present the findings and results for Steps 1 through 4, respectively, listed in Section 3.0.

5.1 WATER AND ENERGY DELIVERY FROM HPS TO PARCEL F

TtEMI estimated storm water and kinetic energy delivery to Parcel F based on the 5-year storm peak flow calculations derived during previous studies that assumed the storm drains were free of debris (YEI 1988) (Appendix B). TtEMI quantified energy delivery to Parcel F using the following equation:

$$K = H\,Q_5\,\gamma \tag{5-1}$$

where:

K	=	Kinetic energy (feet-pounds per second)
H	=	Velocity head (feet)
Q_5	=	5-year storm peak flow (cubic feet per second)
γ	=	Specific weight of water (pounds per cubic foot)

Table 1 summarizes the evaluation results for storm drain flow and kinetic energy potentially delivered to Parcel F. Actual kinetic energy will be less because of the storm water lines inability to carry the 5-year storm flows, except for storm water lines in catchments C5, C8, and C10. Figure 10 shows the estimated 5-year peak flow rates (in gallons per minute) and kinetic energies delivered to Parcel F from catchments C1 through C10.

5.2 EROSIONAL AND DEPOSITIONAL AREAS

Figure 7 shows the HPS areas subject to erosion and deposition. This figure combines Figure 5, which shows slope steepness classes, and Figure 6, which shows slope curvature. Steep slopes with positive curvature shown along the shoreline of HPS (Figures 5 and 6) are natural erosion surfaces that, in most cases, are hardened by riprap or other materials that are armored from erosion. When developing Figure 7, TtEMI assumed that no erosion occurs on gentle slopes (slope steepness of less than 5 percent), regardless of slope curvature. Concave slopes with a steepness of greater than 5 percent were considered to be depositional. TtEMI identified only convex (positive curvature) slopes that are steeper than 5 percent as erosional.

Table 2 summarizes the slope analysis results by catchment. In addition, this table presents the percentage of each catchment area that is paved or bare and vegetated, indicating which areas are less prone to erosion. Figure 7 includes a table summarizing the percentages of each catchment area by landform class. Overall, TtEMI identified 89 percent of HPS surface as depositional and only 11 percent as relatively steep and erosional.

5.3 PREDICTED EROSION RATES

TtEMI obtained a conservative prediction of potential erosion at HPS for each of the 12 catchments using the FSWEPP model (Appendix C). The FSWEPP module "WEPP: Road" was used for all surfaces with a high probability of being compacted. This module could only be applied to slopes measuring less than or equal to 20 percent, and the outsloped, rutted road design was specified. For all surfaces with a low probability of being compacted (slopes greater than 20 percent), TtEMI used the FSWEPP module "Disturbed WEPP." TtEMI specified two soil types such as silty loam and sandy loam when using both "WEPP: Road" and "Disturbed WEPP" to provide a range of predicted erosion values. These soil types are characteristic of surface soil conditions at HPS.

In dry climates, little or no erosion occurs more frequently than in wet climates, so a greater total number of years is necessary to ensure that an adequate number of wet years is used for the analysis (Elliot and others 2000). The simulation period was set at 50 years to provide a wide range of wet and dry years on which to base a conservative estimate of current solids yields. This simulation did not attempt to estimate historic solids yields from HPS to Parcel F that could vary significantly during the fill operations (from 1940 to 1969).

Table 3 summarizes the predicted annual average erosion rates for all catchments at HPS. In addition, Figure 10 shows the estimated potential solid yields from catchments C1 through C10 to Parcel F. The darker arrows on this figure correspond to higher solids yields. Overall, the conservative estimates of erosion rates for HPS are 1.9 to 3.4 tons of solids per acre per year (tons/acre-year). When compared with normal geologic erosion rates of 0.1 ton/acre-year and accelerated erosion rates of 50 tons/acre-year during urban development (Maidment 1993), the predicted erosion rates at HPS appear relatively low.

5.4 EROSION FROM HPS VERSUS SEDIMENT ACCRETION IN PARCEL F

Pier areas adjacent to subcatchments C1A and C1B accumulate more than 0.25 foot of sediment per year (Ogden 1992). Using "WEPP: Road," TtEMI estimated potential annual erosion from subcatchments C1A and C1B as 1.5 and 1.24 kilograms per square meter, respectively (see Table 4, silty loam scenario). In addition, because the simulations were conducted for a 50-year return period, estimates of mean annual erosion from the subcatchments are considered conservatively high.

When converted to units similar to reported sediment accretion in the pier areas, solids delivery from subcatchments C1A and C1B ranges from 0.002 to 0.004 foot per year, which is two orders of magnitude lower than the observed rate of sediment accretion from the Bay. Therefore, sediment accretion from the

Bay is expected to exceed solids delivery from HPS. Table 4 summarizes the calculations used to predict erosion rates at HPS.

6.0 SUMMARY OF FINDINGS

HPS is divided into 10 drainage systems (catchments C1 through C10) that underlie approximately 90 percent of the HPS (YEI 1988). These storm drain systems deliver materials and energy to Parcel F. Two catchments (C11 and C12) are not underlain by storm water systems. Water is transported from HPS to Parcel F by the storm drain systems at catchments C1 through C10 and by groundwater flow at catchments C11 and C12.

The GIS-based DEM model identified probable "pour points" (where water may flow from HPS to Parcel F) for catchments C11 and C12. During a site inspection, TtEMI did not find substantive evidence of significant surface water runoff from these catchments. A conservative estimate of energy delivery from HPS to Parcel F indicates that 85 percent of energy delivery occurs at the following three parcels:

- **Parcel B:** Catchments C2 and C4 deliver 36 percent of the total kinetic energy at discharge points located near Berths 55 and 64
- **Parcel E:** Catchment C1 delivers 36 percent of the total kinetic energy at two discharge points located near Berth 36
- **Parcel C:** Catchment C5 delivers 13 percent of the total kinetic energy at discharge points near Berth 2

Available evidence was insufficient to determine whether a significant energy delivery from HPS to Parcel F occurs at other shoreline locations than those indicated above.

Overall, 89 percent of HPS land surface is depositional, and 11 percent is relatively steep and erosional. In addition, hardening of most surfaces with pavement (58 percent of HPS land surface), is likely to reduce transport of eroded surface materials from HPS to Parcel F.

TtEMI used the FSWEPP to obtain a conservative prediction of potential erosion at HPS for each of the 12 catchments. More than 70 percent of all solids from HPS enter the Bay from four catchments (C1, C2, C4, and C7). Overall, the conservative estimates of erosion rates for HPS are 1.9 to 3.4 tons/acre-year. When compared with normal geologic erosion rates of 0.1 tons/acre-year and accelerated erosion rates of 50 tons/acre-year during urban development (Maidment 1993), the predicted erosion rates at HPS appear relatively low.

Based on comparison of predicted erosion rates from catchments adjacent to pier areas with reported sediment accretion from the Bay, solids delivery from HPS is expected to be much smaller than sediment accretion from the Bay.

In summary, a low potential exists for erosion at HPS. The delivery of energy and solids from HPS to Parcel F is limited to only a few locations. Solids yield from HPS appears much lower than sediment accretion from the Bay.

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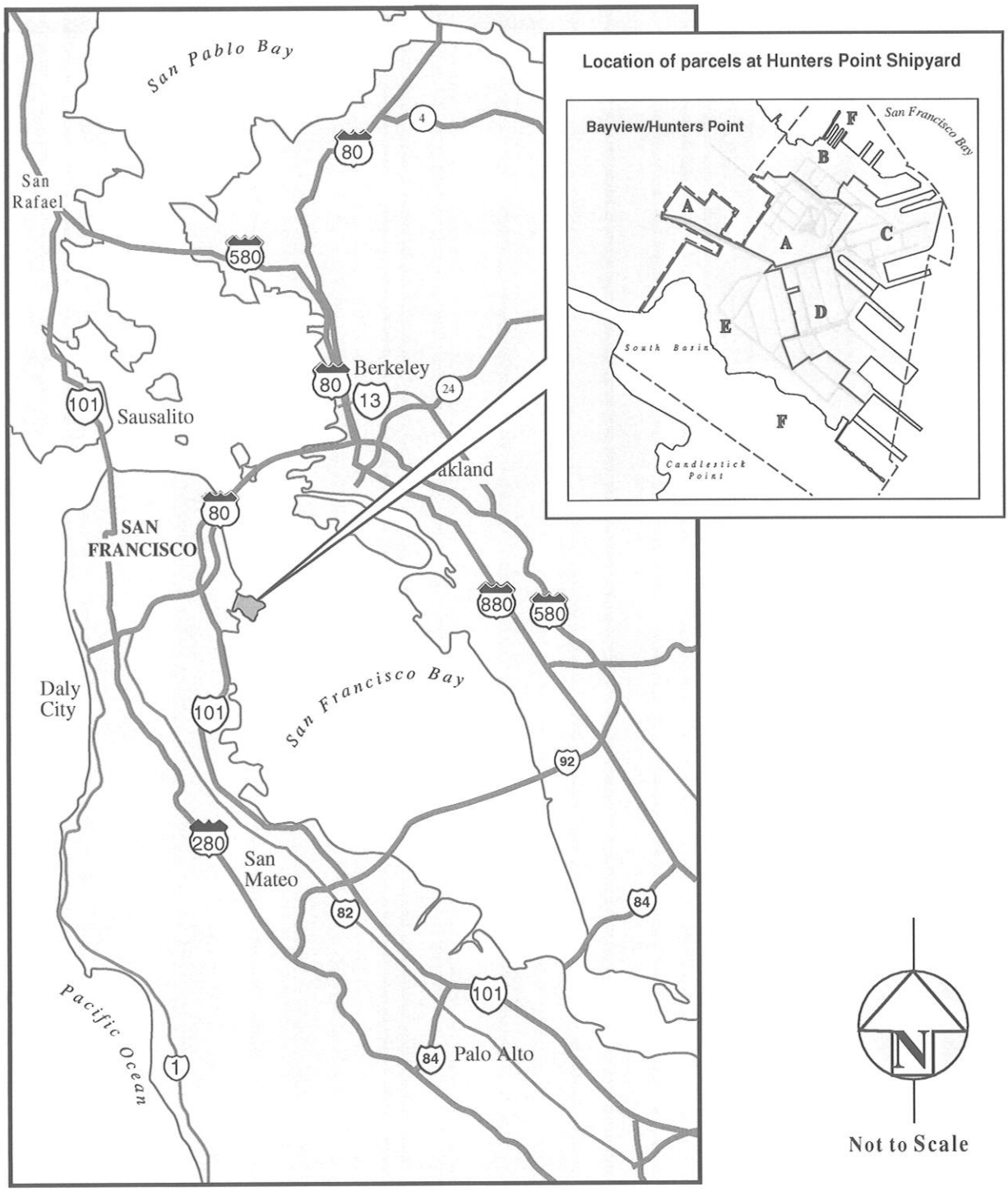

Not to Scale

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 1

LOCATION MAP

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

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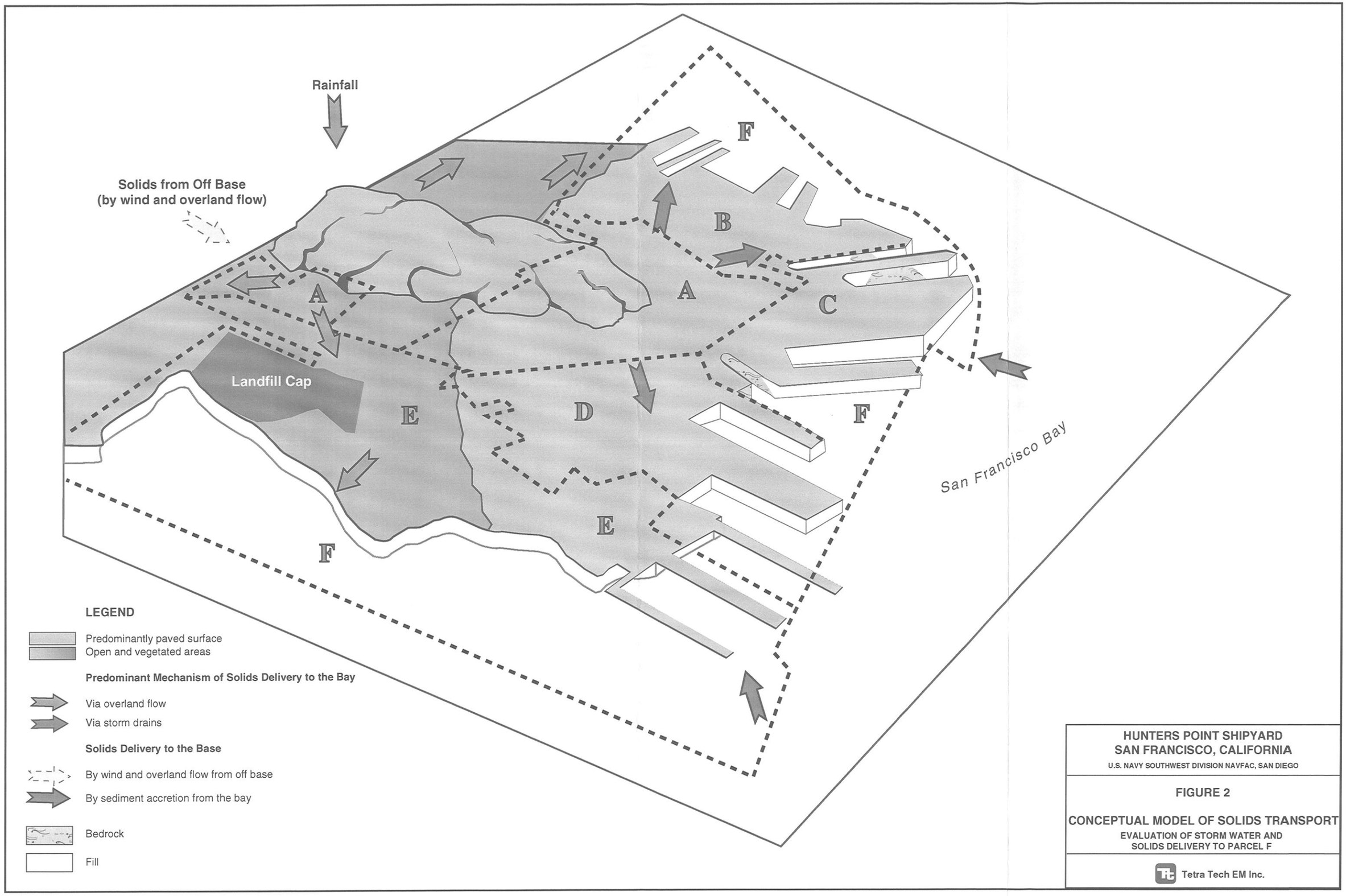


HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

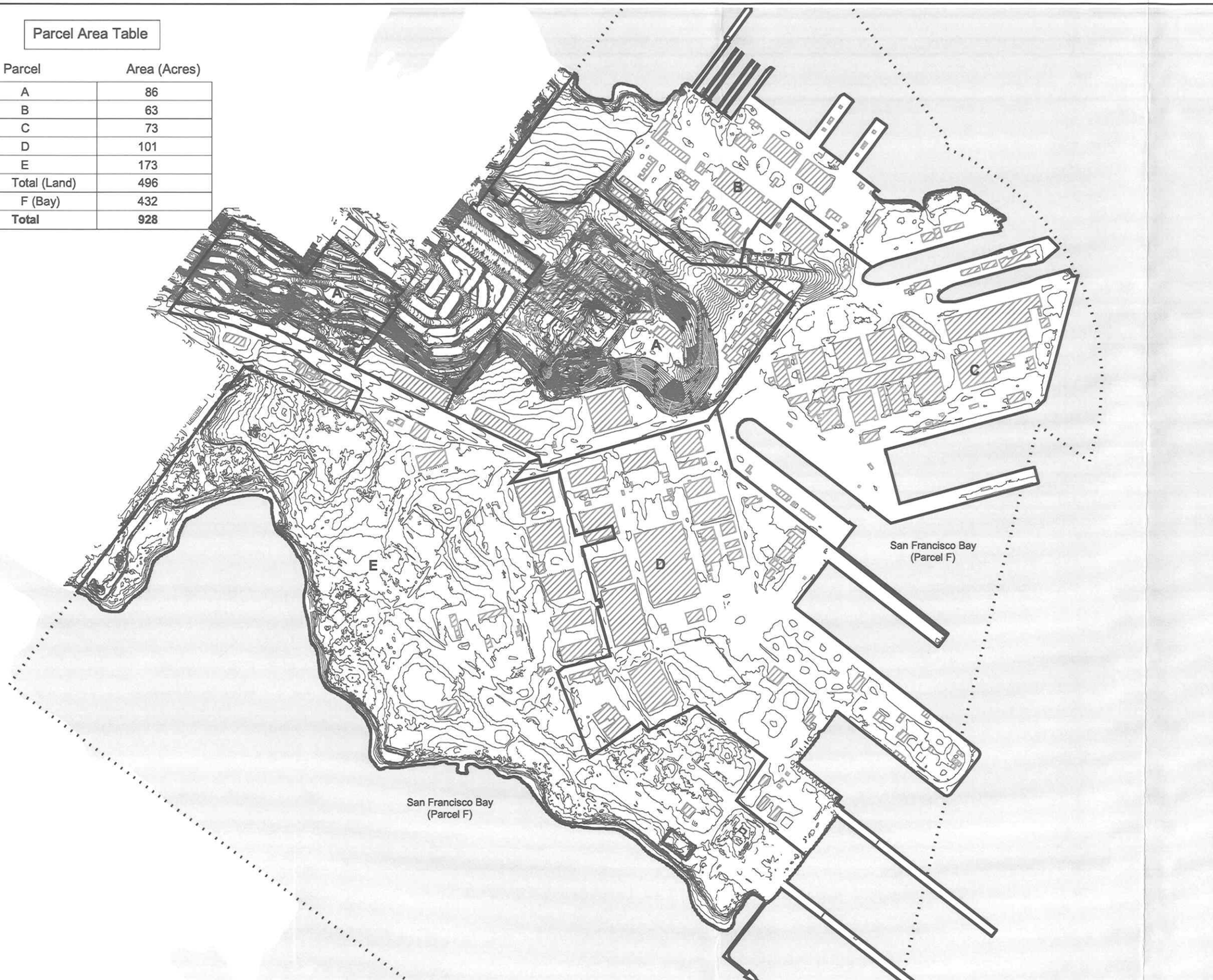
FIGURE 2

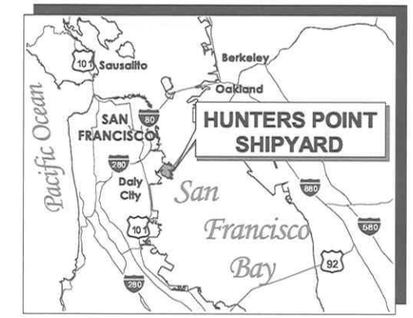
CONCEPTUAL MODEL OF SOLIDS TRANSPORT
EVALUATION OF STORM WATER AND
SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

Parcel Area Table

Parcel	Area (Acres)
A	86
B	63
C	73
D	101
E	173
Total (Land)	496
F (Bay)	432
Total	**928**





Location Map

Legend

Surface Contours

- 2 to 30 feet above msl
- 31 to 70 feet above msl
- 71 to 110 feet above msl
- 111 to 190 feet above msl

- Parcels A, B, C, D, and E Boundary
- Parcel F Boundary
- Building

Notes: Contour Interval = 1 foot
msl = Mean Sea Level

700 0 700

Scale in Feet

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 3

GROUND SURFACE ELEVATION

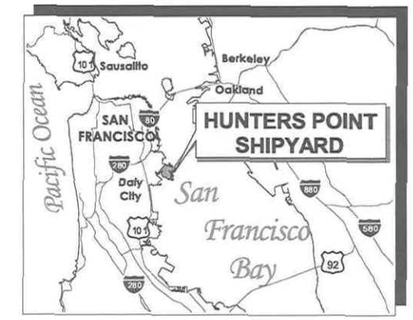
EVALUATION OF STORM WATER
AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

4/17/02 - O:\hunterised2\projectised_one.apr - KDC - Denver

Catchment Area Table

Catchment Name	Area (Acres)
C1	230
C2	57
C3	9
C4	29
C5	43
C6	22
C7	42
C8	35
C9	9
C10	15
C11	25
C12	34



Location Map

Legend

- Storm Sewer Outfalls
- Potential Pour Points from Overland Flow
- Storm Sewer
- Catchment Boundary
- C7 Catchment Identification Number
- Parcel F Boundary
- Building
- Catchment with Potential Overland Flow
- Subcatchments where Predicted Erosion was Compared to Sediment Accretion from the Bay

700 0 700

Scale in Feet

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 4

STORM WATER CATCHMENTS

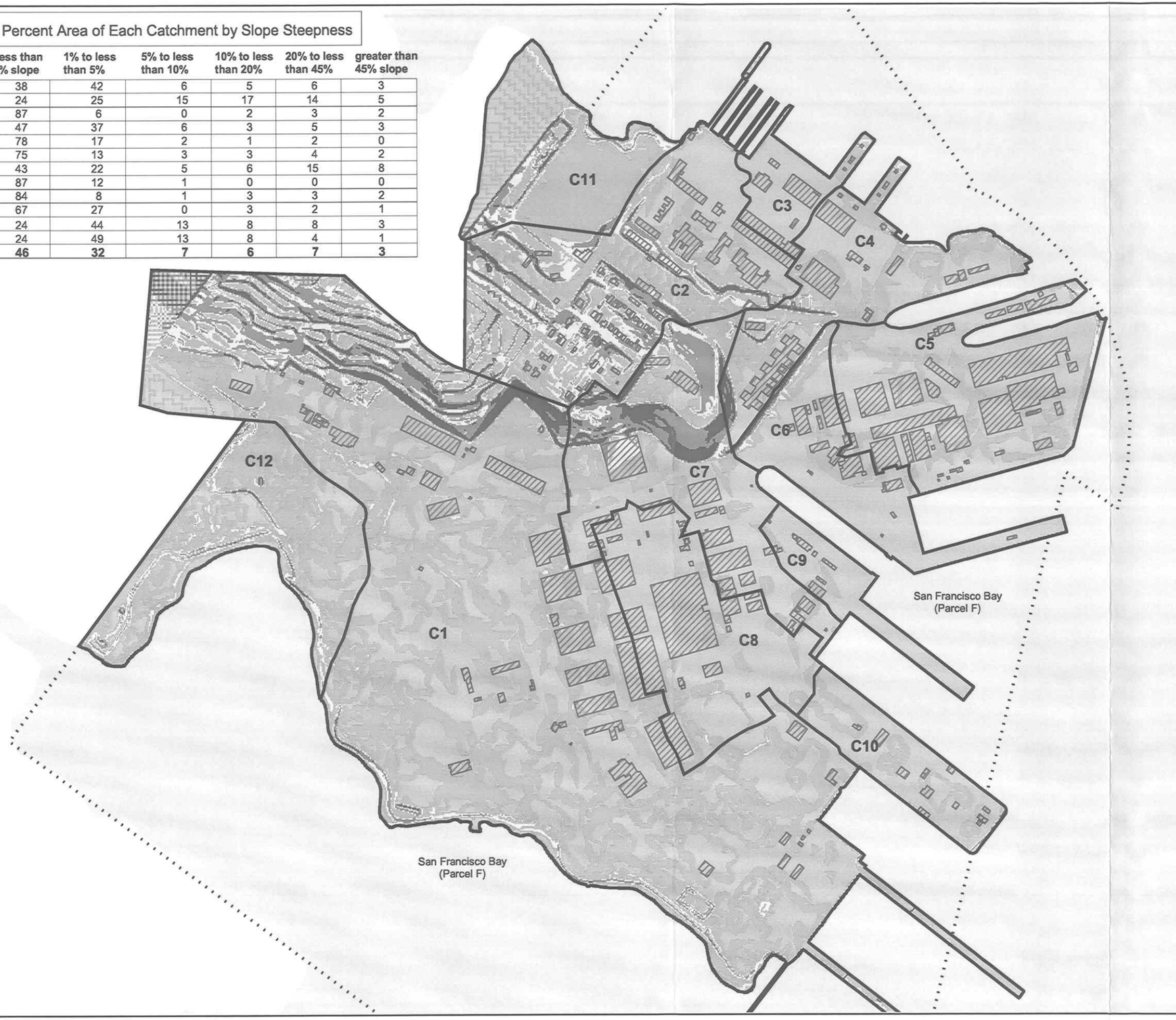
EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

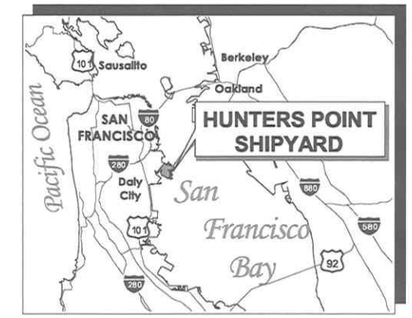
Tetra Tech EM Inc.

4/16/02 - O:\hunters\sed2\projects\report_figures.apr - KDC - Denver

Percent Area of Each Catchment by Slope Steepness

Catchment Name	Less than 1% slope	1% to less than 5%	5% to less than 10%	10% to less than 20%	20% to less than 45%	greater than 45% slope
C1	38	42	6	5	6	3
C2	24	25	15	17	14	5
C3	87	6	0	2	3	2
C4	47	37	6	3	5	3
C5	78	17	2	1	2	0
C6	75	13	3	3	4	2
C7	43	22	5	6	15	8
C8	87	12	1	0	0	0
C9	84	8	1	3	3	2
C10	67	27	0	3	2	1
C11	24	44	13	8	8	3
C12	24	49	13	8	4	1
Basewide	**46**	**32**	**7**	**6**	**7**	**3**





Location Map

Legend

Slope Steepness Class

- Less than 1% slope
- 1% to less than 5% slope
- 5% to less than 10% slope
- 10% to less than 20% slope
- 20% to less than 45% slope
- Greater than 45% slope
- Catchment Boundary
- C7 Catchment Identification Number
- Parcel F Boundary
- Building

N

700 0 700

Scale in Feet

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 5

SLOPE STEEPNESS

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

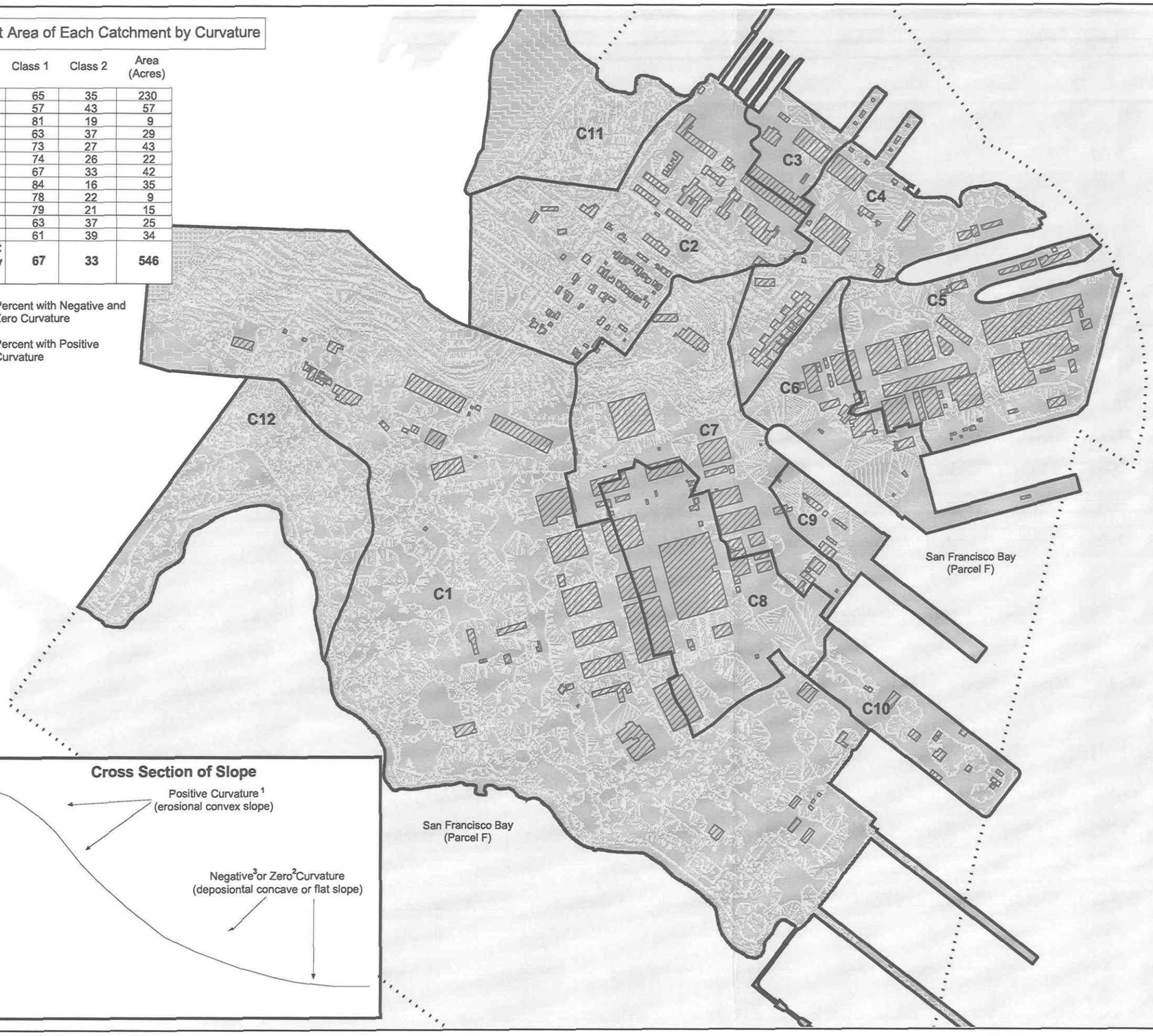
4/16/02 - Q:\hunters\sed2\projects\report figures.apr - KDC - Denver

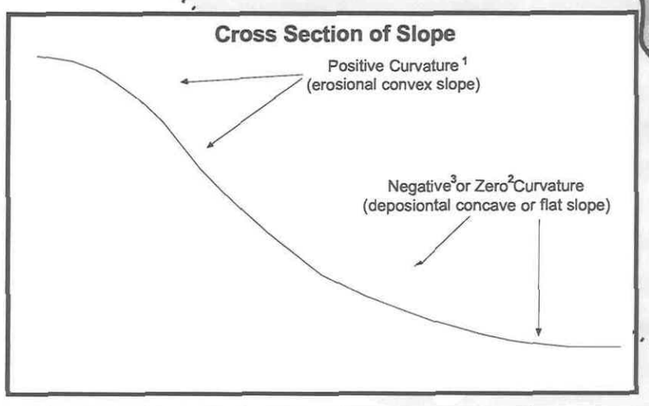
Percent Area of Each Catchment by Curvature

Catchment Name	Class 1	Class 2	Area (Acres)
C1	65	35	230
C2	57	43	57
C3	81	19	9
C4	63	37	29
C5	73	27	43
C6	74	26	22
C7	67	33	42
C8	84	16	35
C9	78	22	9
C10	79	21	15
C11	63	37	25
C12	61	39	34
Percent Total by Area	**67**	**33**	**546**

Class 1 - Percent with Negative and Zero Curvature

Class 2 - Percent with Positive Curvature





Location Map

Legend

Slope Curvature Class

- Negative or Zero Curvature (Depositional concave or flat slopes)
- Positive Curvature (Erosional convex slopes)
- Catchment Boundary
- C7 Catchment Identification Number
- Parcel F Boundary
- Building

Notes:

1. A positive curvature indicates that the surface is upwardly convex.
2. A zero curvature indicates that the surface is flat.
3. A negative curvature indicates that the surface is upwardly concave.

700 0 700

Scale in Feet

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 6

SLOPE CURVATURE

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

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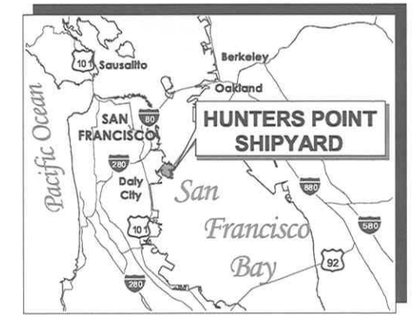
Percent Area of each Catchment by Erosion Class

Catchment Name	Class 1	Class 2	Class 3	Area (Acres)
C1	79	11	10	230
C2	49	25	26	57
C3	93	1	5	9
C4	83	8	9	29
C5	95	2	3	43
C6	88	6	6	22
C7	65	16	18	42
C8	99	1	0	35
C9	91	4	5	9
C10	94	3	4	15
C11	69	18	13	25
C12	74	14	12	34
Percent Total by Area	**78**	**11**	**11**	**546**

Class 1 - Depositional (less than 5% slope)

Class 2 - Depositional (greater than 5% slope and zero or negative curvature)

Class 3 - Erosional (greater than 5% slope and positive curvature)



Location Map

Legend

Landform Class

- Depositional (less than 5% slope)
- Depositional (greater than 5% slope and zero or negative curvature)
- Erosional (greater than 5% slope and positive curvature)
- Catchment Boundary
- C7 Catchment Identification Number
- Parcel F Boundary
- Building

Notes:

1. A positive curvature indicates that the surface is upwardly convex.
2. A zero curvature indicates that the surface is flat.
3. A negative curvature indicates that the surface is upwardly concave.

700 0 700

Scale in Feet

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 7

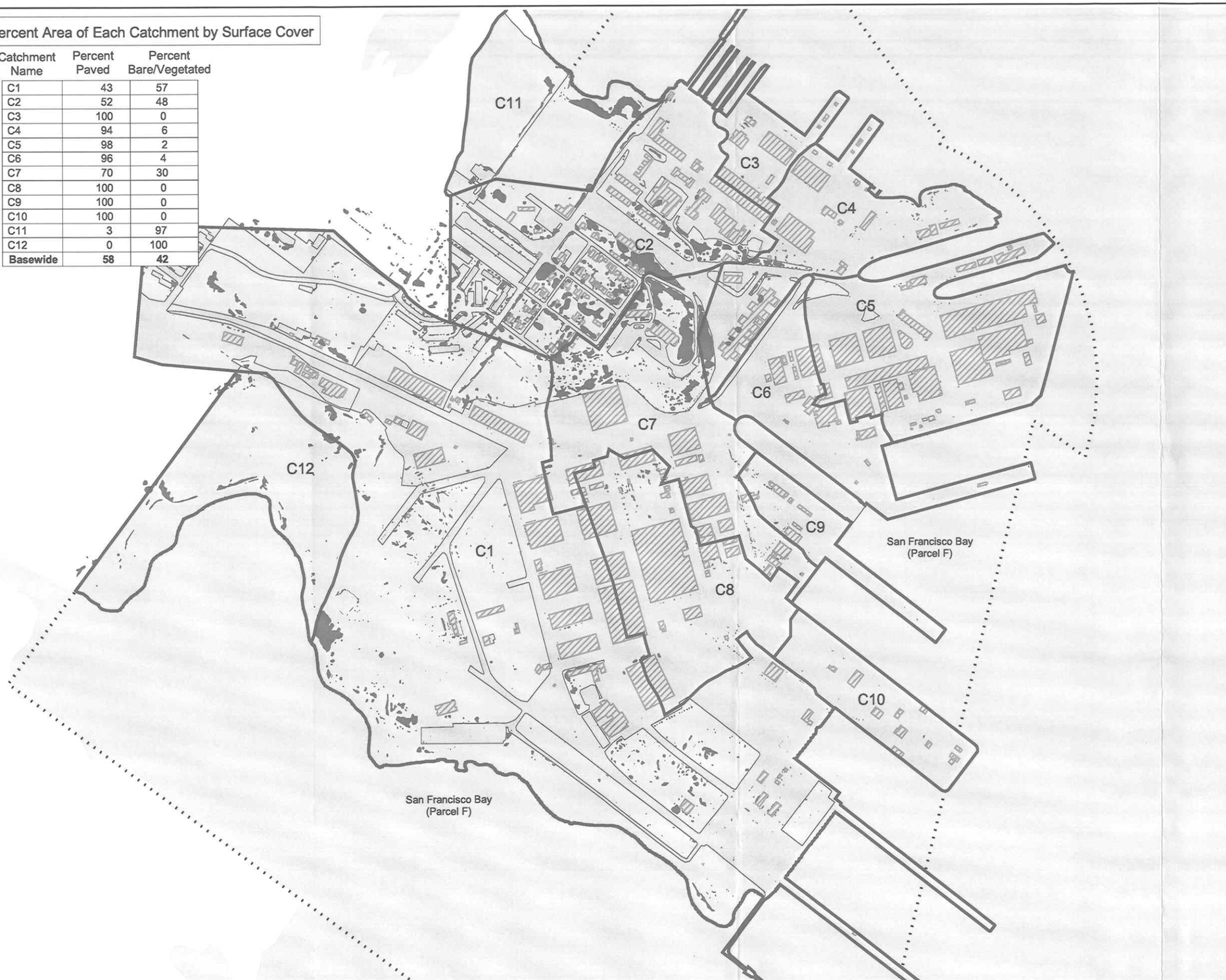
DEPOSITIONAL AND EROSIONAL SURFACES
EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

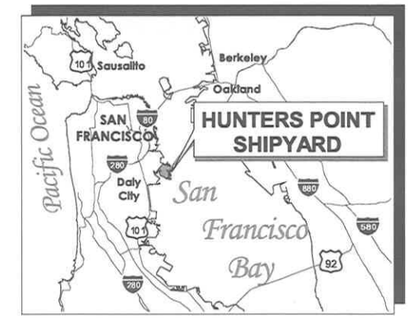
Tetra Tech EM Inc.

4/17/02 - O:\hunters\sed2\projects\report_figures.apr - KDC - Denver

Percent Area of Each Catchment by Surface Cover

Catchment Name	Percent Paved	Percent Bare/Vegetated
C1	43	57
C2	52	48
C3	100	0
C4	94	6
C5	98	2
C6	96	4
C7	70	30
C8	100	0
C9	100	0
C10	100	0
C11	3	97
C12	0	100
Basewide	**58**	**42**





Location Map

Legend

- Paved Surface or Building
- Unpaved Surface
- Tree or Shrub Cover
- Building
- Catchment Boundary
- C7 Catchment Identification Number
- Parcel F Boundary

Note:

3.6 percent of Hunters Point Shipyard is covered by tree and shrubs.

700 0 700

Scale in Feet

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 8

SURFACE COVER TYPE

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

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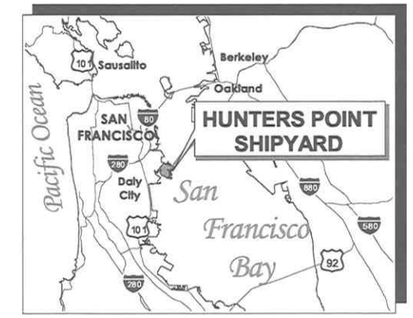


Location Map

Legend

- Storm Drain Inlet

Flow Length Class

- 0 - 50 feet
- 51 - 100 feet
- 101 - 150 feet
- 151 - 200 feet
- 201 - 250 feet
- 251 - 300 feet
- 301 - 800 feet
- 801 - 1,200 feet
- 1,201 - 1,702 feet
- Catchment with Potential Overland Flow
- Catchment Boundary
- C7 Catchment Identification Number
- Parcel F Boundary

700 0 700

Scale in Feet

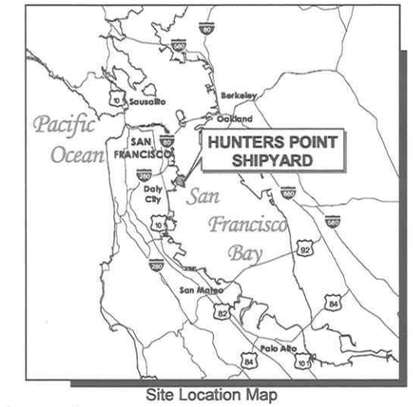
HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 9

FLOW LENGTH TO STORM DRAIN INLETS
EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

4/16/02 - O:\hunters\sed2\projects\report_figures.apr - KDC - Denver



Site Location Map

Legend

- Storm Sewer Outfall
- Catchment Boundary
- Parcel F Boundary
- C7 Catchment Identification Number

Surface Cover

- Paved
- Unpaved
- Surface Debris Pile
- Trees or Shrubs

599 ft-lbs/sec
10,833 gallons/minute
47 tons/year

- Estimated Potential Solids Yield (Annual)
- Peak Flow Rate (5 Year Storm)
- Peak Kinetic Energy

Notes: Darker arrow colors indicate greater predicted solids yields, peak flows, and kinetic energies from respective catchments.

ft-lbs/sec feet-pounds per second

N

1000 0 1000

Scale in Feet

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE 10

PREDICTED SOLIDS YIELDS, PEAK FLOWS, AND KINETIC ENERGIES
EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

04-19-2002 v:\hunters point\projects\soil to bay pathway\erosion potential.apr TIEM-SF kevin.ernst

TABLE 1

CONSERVATIVE ESTIMATE OF STORM WATER AND KINETIC ENERGY DELIVERY TO PARCEL F EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F HUNTERS POINT SHIPYARD, SAN FRANCISCO, CALIFORNIA

Delivery	Catchments[a]									
	C1	C2	C4	C5	C6	C7	C8	C9	C3	C10
Storm Water Flow[b] (cubic feet per second)	158	57	42	35	24	17	37	10	12	12
Kinetic Energy[c] (feet-pounds per second)	4,920	2,850	2,107	1,727	599	543	458	296	147	74
Percent of Total[d]	36	21	15	13	4	4	3	2	1	1

Notes:

a Catchments C11 and C12 are not included because a predominant mechanism of water and energy delivery from these catchments is by groundwater discharge.

b Estimates were derived using the rational method equation for a 5-year storm event

c Actual kinetic energy will be less because of the storm drains' inability to carry 5-year storm flows, except for catchments C5, C8, and C10.

d Percent of storm water flow or kinetic energy delivery from a given catchment relative to cumulative delivery from catchments C1 through C10.

TABLE 2

PERCENT OF CATCHMENT AREA BY SLOPE CLASS AND SURFACE COVER TYPE
EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F
HUNTERS POINT SHIPYARD, SAN FRANCISCO, CALIFORNIA

Catchment	Percent of Catchment Area							
	Slope Class (%)						Paved	Bare/ Vegetated
	<1	1-5	5-10	10-20	20-45	>45		
C1	38	42	6	5	6	3	43	57
C2	24	25	15	17	14	5	52	48
C3	87	6	0	2	3	2	100	0
C4	47	37	6	3	5	3	94	6
C5	78	17	2	1	2	0	98	2
C6	75	13	3	3	4	2	96	4
C7	43	22	5	6	15	8	70	30
C8	87	12	1	0	0	0	100	0
C9	84	8	1	3	3	2	100	0
C10	67	27	0	3	2	1	100	0
C11	24	44	13	8	8	3	3	97
C12	24	49	13	8	4	1	0	100
Basewide	**46**	**32**	**7**	**6**	**7**	**3**	**58**	**42**

TABLE 3

PREDICTED ANNUAL EROSION RATES
EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F
HUNTERS POINT SHIPYARD, SAN FRANCISCO, CALIFORNIA

Catchment	Silty Loam		Sandy Loam		Catchment Area (acres)	Mean Annual Erosion[a] (tons/year)
	Weighted Average (kg/m^2)	Weighted Average (tons/acre)	Weighted Average (kg/m^2)	Weighted Average (tons/acre)		
C1	1.1	4.8	0.7	3.1	230	915
C2	1.3	5.7	0.7	3.1	57	250
C3	0.4	1.7	0.2	1.0	9	12
C4	1.0	4.3	0.6	2.6	29	101
C5	0.5	2.2	0.3	1.4	43	76
C6	0.6	2.7	0.4	1.6	22	47
C7	1.3	5.7	0.7	3.2	42	185
C8	0.3	1.4	0.2	0.9	35	40
C9	0.3	1.4	0.2	0.8	9	10
C10	0.7	3.1	0.4	1.9	15	37
C11	1.0	4.6	0.4	1.7	25	78
C12	0.8	3.4	0.2	1.1	34	77
Basewide	**0.8**	**3.4**	**0.4**	**1.9**	**546**	**1,828**

Notes: Estimates are for two soil types characteristic of surface soil conditions at Hunters Point Shipyard.

a Mean annual erosion is calculated for each catchment by averaging the estimates for silty loam and silty sand.

kg/m^2 Kilogram per square meter

tons/acre Tons per acre

TABLE 4

SOLIDS DELIVERY FROM TWO SUBCATCHMENTS VERSUS SEDIMENT ACCRETION AT PARCEL F
EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F
HUNTERS POINT SHIPYARD, SAN FRANCISCO, CALIFORNIA

Subcatchment	Area (m^2)	Predicted Erosion Rate[a] (kg/m^2)	Eroded Mass (kg)	Bulk Density[b] (kg/m^3)	Volume Delivered (m^3)	Solids Delivery Rate (feet/year)	Accretion[c]/ Erosion Ratio
C1A	17,925	1.5	26,887	1,700 1,200	15.8 22.4	0.003 0.004	86 60
C1B	21,239	1.24	26,336	1,700 1,200	15.5 21.9	0.002 0.003	105 74

Notes:

a Subcatchments C1A and C1B are in catchment C1 (Figure 4). For each subcatchment, simulations were conducted using the module "WEPP: Road."

b Estimates of solids delivery rates are based on assumed bulk densities of sediment accreted at Parcel F.

c A low accretion rate of 0.25 foot per year (Ogden Beeman & Associates, Inc. 1992) was used for comparison with predicted annual erosion rate.

kg Kilogram

kg/m^2 Kilogram per square meter

m^2 Square meter

m^3 Cubic meter

WEPP Water Erosion Prediction Project

Source: Ogden Beeman & Associates, Inc. 1992. "Sediment Budget Study for San Francisco Bay – Final Report." February 29.

APPENDIX A

GIS APPLICATION FOR EVALUATION OF SOLIDS TRANSPORT HUNTERS POINT SHIPYARD, SAN FRANCISCO, CALIFORNIA

CONTENTS

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4.0	RELATION OF TOPOGRAPHIC CATCHMENTS TO STORM SEWER SYSTEM	A-3
5.0	SLOPE AND CURVATURE	A-3
6.0	PREPARATION OF INPUT DATA FOR THE FSWEPP MODEL	A-4
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ABBREVIATIONS AND ACRONYMS

DEM	Digital Elevation Model
FSWEPP	Forest Service Water Erosion Prediction Project
GIS	Geographic information system
HPS	Hunters Point Shipyard
TtEMI	Tetra Tech EM Inc.

1.0 INTRODUCTION

Based on a topographic elevation map with a 1-foot contour interval for Hunters Point Shipyard (HPS), Tetra Tech EM Inc. (TtEMI) developed a geographic information system (GIS)-based Digital Elevation Model (DEM). TtEMI used the DEM to digitally generate a flow direction grid, potential watercourses, boundaries of HPS lands that contribute to the watercourses, and stream networks at HPS and the surrounding area based on topography (see Figure 3 in the main document). This appendix briefly describes the development of the DEM and how it was used to identify areas subject to erosion or deposition and to prepare input parameters for a physically based erosion model.

2.0 DEM DEVELOPMENT

An important application of the GIS is the development of a DEM. DEMs are used to identify features such as ridges, valley bottoms, and drainage networks and to quantify watershed (catchment) and channel properties, including size, length, and slope. Quality and resolution of the DEM helps to achieve accurate representation of these features.

Watersheds are lands enclosed by a continuous surface drainage divide that lie upslope from a specified point (U.S. Geological Survey 1978). As used in the GIS, this downslope point is called a "pour point." Watersheds generally include thousands of acres of land. For the purpose of this document, the term catchment is used to identify watersheds that are less than 200 acres in size. Subcatchments are areas within the catchments that drain to a specific point of land within a catchment.

Automated watershed delineation using the GIS technology has rapidly developed over the past two decades. As a result, a number of software tools are available. These software tools help to identify surface water flow pathways at HPS. By identifying surface water pathways, TtEMI gained further understanding of the potential transport of solids from HPS to San Francisco Bay (referred to as Parcel F). In addition, GIS can store, manage, and process large amounts of data for an evaluation of properties that affect erosion at HPS. The following properties (or attributes) were evaluated for this project to help understand surface water flow and associated solids transport:

- Elevation
- Land slope and curvature
- Flow direction and distance

- Catchment boundaries, areas, and locations of low elevation "grid cells"
- Storm sewer drainage system inlets, flow paths, and outfalls
- Land cover (paved, vegetated, or bare soil)

TtEMI developed a DEM to help evaluate the potential for storm water and solids delivery from HPS to Parcel F. This model was also used to evaluate potential flow directions based on topography. Most of HPS is relatively flat; therefore, small topographic variations can result in a large degree of uncertainty for the modeled drainage pathways. As a result, TtEMI used a digital topographic elevation map with 1-foot contour intervals to achieve a sufficient level of detail for the overland flow evaluation at HPS. However, drainage identification in flat areas is an approximation and may not accurately reflect the actual drainage pattern in areas that are too small to be resolved at the resolution of the DEM (Garbrecht and Martz 1999).

3.0 OVERLAND FLOW EVALUATION USING THE DEM

Based on sensitivity analysis, TtEMI found an 8- by 8-foot grid cell size to be adequate for delineating catchments at HPS. The standard methodology for delineating streams and catchments at HPS was applied using the DEM.

The standard methodology is based on the eight-direction pour-point algorithm. This algorithm uses information from the eight surrounding cells to determine flow magnitude and direction for a given cell, assuming flow is driven by gravity. Therefore, flow will always be toward the low elevation grid cells (sinks), with flow size increasing toward the sink outlet (lowest point in the subcatchment or the pour point).

The following approach was used to identify potential overland flow pathways at HPS:

1. Convert a digital topographic elevation map with 1-foot contour intervals to a grid of 8- by 8-foot cells.
2. Determine flow direction, identifying the cell toward which water will flow.
3. Calculate flow accumulation, which is achieved by evaluating the drainage area that feeds into each cell.
4. Identify the stream cells. Streams cells are flagged based on the specified threshold. For HPS, when 2,000 cells are identified as feeding into a cell, that cell is flagged as a stream cell.

5. Link the stream cells.

6. Establish boundaries for subcatchments and combine into catchments with pour points at Parcel F.

Once the stream cells are identified, potential overland flow pathways become apparent. Each subcatchment, which includes a minimum of 2,000 cells, has a pour point. The pour point is the location where all water within the subcatchment may potentially drain. Upland subcatchments feed into downgradient subcatchments, until a pour point is identified at the HPS-Parcel F interface. Figure 4 of the main document shows the pour points at this interface for catchments that are not drained by the storm sewers. This figure also shows the storm sewer catchments and their outfalls to the Bay. For this analysis, TtEMI combined the inland subcatchments into catchments that have the hydrologic function of watersheds.

4.0 RELATION OF TOPOGRAPHIC CATCHMENTS TO STORM SEWER SYSTEM

The storm sewer system transports water across the catchment boundaries. Therefore, storm sewers override the topographic features that define catchment boundaries. For this analysis, catchment boundaries underlain by storm sewers correspond to those presented in the study by YEI Engineers, Inc. (1998).

Some lands within catchments delineated for this study are not within HPS. Lands that are external to HPS have residential and commercial developments. These lands are drained by the municipal storm sewer system and were not included as part of the HPS catchment areas.

5.0 SLOPE AND CURVATURE

The dominant factors affecting erosion are slope of the land surface and landform curvature. TtEMI quantified these factors using the DEM model. Slope was examined in detail and divided into classes by steepness, and the degree of slope for each 8- by 8-foot grid cell was determined. Application of this attribute provided quick assessment of areas and catchments with the highest erosive potential. Cells with the steepest slope typically represent the highest erosive potential. Figure 5 in the main document shows the distribution of slopes by steepness at HPS.

TtEMI also evaluated landform curvature to identify areas of potential erosion and deposition. Using the DEM calculation for each grid cell, HPS was divided into two categories: (1) areas with positive curvature and (2) areas with negative or zero curvature. A positive curvature indicates that the land surface is upwardly convex at the grid cell center, representing an erosional surface. A negative or zero

curvature indicates that the surface is upwardly concave or flat at the grid cell center, representing a depositional surface. Figure 6 in the main document shows the distribution of areas with positive and negative or zero curvatures. Figure 7 in the main document shows the HPS areas subject to erosion and deposition. This figure combines Figures 5 and 6 and shows that no erosion occurs on gentle slopes (slope steepness of less than 5 percent), regardless of slope curvature. Concave slopes with a steepness of greater than 5 percent are shown as depositional. Only convex (positive curvature) slopes steeper than 5 percent are represented on Figure 7 as erosional.

6.0 PREPARATION OF INPUT DATA FOR THE FSWEPP MODEL

GIS was also used to develop input parameters for a physically based soil erosion model, Forest Service Water Erosion Prediction Project (FSWEPP) (see Appendix C for additional details). For example, the FSWEPP model required the percentage of a catchment area that is paved or vegetated, since surface cover type will influence erosive potential. The GIS generated approximate values for factors that influence erosion rates: slope steepness, vegetation, land use, flow path length, and others.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The GIS application, including the DEM model and various coverages, was essential to this evaluation because it supported the modeling process and enhanced presentation of the results. TtEMI continues to develop HPS's GIS to obtain more sophisticated and site-specific calculations of solids delivery to Parcel F. In addition, further development of the GIS is required to (1) expedite preparation of valid input parameters into physically based erosion prediction model and (2) enhance the visualization process of erosion model predictions.

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APPENDIX B

EVALUATION OF STORM DRAIN FLOW
HUNTERS POINT SHIPYARD, SAN FRANCISCO, CALIFORNIA

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ABBREVIATIONS AND ACRONYMS

GIS	Geographic information system
HPS	Hunters Point Shipyard
in/hr	Inch per hour
Tc	Time of concentration
TtEMI	Tetra Tech EM Inc.
YEI	YEI Engineers, Inc.

1.0 INTRODUCTION

When evaluating potential transport of solids from Hunters Point Shipyard (HPS) to the San Francisco Bay (hereafter referred to as Parcel F), it is important to estimate the surface water flow within the storm sewer system. In 1988, YEI Engineers, Inc. (YEI) conducted a storm sewer study at HPS, and the subsequent report concluded that the sewers drain most of the HPS land surface (YEI 1988).

Section 2.0 discusses Tetra Tech EM Inc.'s (TtEMI) approach for calculating representative peak storm sewer flows using the geographic information system (GIS) developed for HPS.

Section 3.0 summarizes YEI's storm sewer study and discusses the basewide applicability of the study's results. TtEMI specifically reviewed the following items:

1. YEI calculations of storm water flow
2. Hydrologic characteristics of the storm water drainage area upstream of the storm sewers
3. Hydraulic limitations of the existing storm sewers
4. Calculations demonstrating the storm sewers' ability to accommodate 2-year and 5-year rainfall events

Section 4.0 summarizes TtEMI's approach and the results of the YEI study. Section 5.0 lists the references used to prepare this appendix, and is followed by the figures.

2.0 APPROACH

The existing storm sewer system at HPS was developed in phases, eventually consisting of 10 independent drainage systems or catchments. Each catchment has its own tributary drainage area and an outfall into Parcel F. The 10 catchments at HPS, initially discussed by YEI as drainage systems A through J (YEI 1988), are designated C1 through C10 in this appendix (Figure B-1). Flow calculations and procedures presented in this appendix are applicable to each catchment.

TtEMI analyzed the results presented in the YEI report and evaluated the basewide applicability of the results using the following steps:

1. Locate storm sewers discussed in the YEI report and compare their locations with current GIS maps to verify accuracy of the information
2. Assess methods and parameters presented in the YEI report to evaluate the storm sewers' ability to accommodate storm water events

3. Develop a means to extend the methods and parameters outlined in the YEI report, so they can be applied to all HPS storm sewers, if appropriate

4. Develop a similar method of applying flow evaluation parameters using GIS

TtEMI applied the following general assumptions throughout the above-stated approach:

- All rainfall within catchments C1 through C10 is delivered through the storm sewer systems, and no overland flow occurs.
- All storm sewers discharge to Parcel F and are independent of the sanitary sewers.
- During hydraulic analysis, TtEMI assumed the storm sewers were free of debris. While many storm sewers are free of debris, flow is sometimes obstructed.
- Tide level was at or below the top of the sewer pipe crown.

It was beyond the scope of this task to complete a hydraulic analysis of the entire storm sewer system at HPS. In addition, YEI's report did not discuss invert elevation data, and limited invert elevation data are available in the GIS for such an analysis. Therefore, only a "representative" hydraulic analysis using estimated inverts was completed. TtEMI assumed the hydraulic characteristics from that single representative section were true for catchments C1 through C10. TtEMI used available invert elevations data to come up with the "representative" section based on the YEI report discussion as well as typical storm sewer design parameters.

3.0 METHODOLOGY OF STORM DRAIN FLOW EVALUATION

This section details the methodology followed to address Steps 1 through 4 mentioned above.

3.1 STORM SEWER LOCATIONS

TtEMI identified the location of each storm sewer system in the YEI report using the sewer diameters, sewer length, and street locations as reference points (Figure B-1). The sewer locations are consistent with those locations presented on Figure 4 of the main text.

3.2 ASSESSMENT OF YEI REPORT METHODS AND PARAMETERS

There are two limiting properties in storm sewer flow calculations: (1) hydrologic properties that influence the site's ability to generate rainfall runoff, and (2) hydraulic properties that control a storm sewer's ability to transport rainfall runoff.

3.2.1 Hydrologic Properties

YEI used the common "Rational Method" to calculate flows and determine rainfall runoff for the HPS area. This method is a simple calculation commonly used during the implementation of sewer systems, where peak storm sewer flow relates directly to rainfall intensity. The calculation is intended for small catchments (up to about 200 acres). Following the assumptions outlined in Section 2.0 and noting that catchments C2 through C10 (except C1) are smaller than 200 acres, the "Rational Method" equation can be applied for each catchment. Catchment C1 is just slightly greater than 200 acres, so the calculations for this catchment were conducted in a similar way as for other catchments. The "Rational Method" equation is:

$$Q = A * I * C \qquad \text{(B-1)}$$

where:

Q	=	Flow discharge in cubic feet per second
A	=	Drainage area contributing flow to the sewer (acres)
I	=	Rainfall intensity in inches per hour (in/hr)
C	=	Runoff coefficient (dimensionless) describing the drainage area's propensity to contribute rainfall runoff

YEI calculated the total acreage of the storm sewer drainage areas to be 420 acres. The HPS GIS calculates the total area of catchments C1 through C10 as 491 acres (see Figure 4 of the main document). However, the GIS calculation included some small storm sewers immediately adjacent to Parcel F that were not accounted for in the YEI report. However, differences in the acreages cited in the YEI report and in the GIS model are considered to be in a reasonable agreement.

Rainfall intensity for a given area was based on rainfall curves for nearby areas in in/hr. The 60-minute rainfall intensity values used in YEI's study are similar to those values cited in a report prepared by Hydrocomp, Inc. (2001). Therefore, the values used in YEI report for other rainfall durations are considered to be accurate.

Coefficient C ranges from 0 to 1. In YEI's study, the coefficient was set at 0.8, a value typical of urbanized areas with large paved areas. Since approximately 80 percent of catchments C1 through C10 have urbanized surface features, this value appears to be appropriate for this evaluation.

3.2.2 Hydraulic Properties

The storm sewer system's ability to convey water (or system hydraulics) is an integral part of determining peak flows. When rainfall runoff greatly exceeds the full-pipe capacity of the sewer system, water will pressurize the sewer, creating surcharge conditions and sometimes causing storm water to pool above the manholes.

A complete hydraulic analysis of a complicated system, such as the one at HPS, is a significant undertaking. TtEMI did not attempt this analysis during this review. In addition, no invert elevation data were presented in the YEI report, and only limited invert elevation data were available in the GIS. These data are necessary for determining pipe slopes. As a result, TtEMI completed a hydraulic analysis for one representative section of the storm sewer using estimated inverts only. Hydraulic characteristics from that single representative section were assumed to be true for all catchments. The invert specifications for the representative section were based on data from the YEI report, as were the typical storm sewer design parameters listed below:

- Surface elevation at each manhole or catch basin
- Pipe length
- Pipe diameter
- Flow
- A roughness coefficient (n) of 0.013

  TtEMI used the following Manning's equation (Lindeburg 2001):

$$V=[(D)^{0.67}*(S)^{0.50}]/\ [n*8.888] \qquad \text{(B-2)}$$

  where:

  V = Velocity (feet per second)

  D = Diameter (inches)

  S = Pipe slope (feet per feet)

  n = Roughness coefficient

- Slope such that the minimum velocity is 3 feet per second in any pipe section (Lindeburg 2001)
- Pipe crown (4 feet deep) (Lindeburg 2001).

For this evaluation, TtEMI selected the largest storm sewer system (catchment C1) as representative (Figure B-1). TtEMI designed the hypothetical slope by setting the crowns, or the top of the pipe, at least 4 feet below ground surface. Next, TtEMI determined the corresponding velocity and, if it was measured at less than 3 feet per second, the velocity was increased by raising the slope. Using these invert slopes, TtEMI computed the sewer capacity and compared it with rainfall inflow.

In many cases, individual sections of the sewer surcharged. Overall, the hypothetical sewer had the ability to convey inflow for both a 2-year and 5-year storm event. Figures B-2 and B-3 show the profile of the hypothetical sewer for a 2-year flow and a 5-year flow, respectively. As shown on Figure B-3, the sewer becomes surcharged when the hydraulic gradeline rises above the crown of the sewer. This surcharge indicates the hypothetical sewer would marginally accommodate runoff associated with a 5-year storm event. Therefore, TtEMI assumed the sewers at HPS will have the ability to convey inflows up to the 5-year level with no hydraulic restrictions. This assumption is consistent with the assumptions listed in Section 2.0 of this appendix.

3.3 EXTENDING YEI'S METHODS TO EVALUATE ALL STORM SEWERS

The sections below present an approach to represent storm sewer peak flows for all storm sewers at HPS. This approach can be easily applied using data compiled from the HPS GIS database. In addition, all parameters needed for flow calculations are fixed or directly related to an area and sewer length. Since area and sewer length can be extracted directly from GIS, calculation of peak flows can be immediately conducted in the current HPS GIS.

3.3.1 Catchment Area, Sewer Length, Sewer Diameter, and Runoff Coefficient

Catchment area, sewer length, and sewer diameter can be compiled from the existing GIS. Therefore, TtEMI can estimate flow for any point in a particular sewer system and still be consistent with the approach used by YEI (1988). To be consistent with the YEI report and because of the large paved area at HPS, TtEMI set the runoff coefficient (*C*) at 0.80 in all cases.

3.3.2 Time of Concentration

Time of concentration (Tc) represents the time it presumably takes runoff to reach the storm sewer outlets from the farthest reach of the drainage area. In the YEI report, the Tc ranged from 5 to 50 minutes in the (YEI 1988). These values were compared with estimates from two methods outlined in *Civil Engineering Reference Manual* (Lindeburg 2001). In almost all cases, Tc values in the YEI report were shorter than

those values from the *Civil Engineering Reference Manual* estimates. Since shorter Tc values result in higher flows, Tc values based on the YEI report will lead to more conservative results.

Using all data from the storm sewer outlets presented in the YEI report, TtEMI developed a linear regression relationship between Tc and sewer drainage area and sewer length (Figures B-4 and B-5). The reasonably strong correlation of Tc data with both sewer drainage area ("R^2" value greater than 91 percent) and sewer length ("R^2" value greater than 82 percent) suggests that the regression equations can be used to estimate Tc for all storm sewers at HPS.

Tc is a function of both the storm sewer drainage area (hydrology) and storm sewer length (hydraulics). Therefore, the suggested procedure to calculate estimated Tc for a given point is to use both drainage area and mainline sewer length, and then average the two estimates to obtain an adopted value for Tc.

1. T_{c1} *[minutes]* = 0.1661x + 10.523 (where "x" is the area [acres])
2. T_{c2} *[minutes]*= 0.0066x + 4.2629 (where "x" is the sewer length [feet])
3. T_c(adopted) *[minutes]* = average of T_{c1} and T_{c2}
4. The minimum value of T_c (adopted) (for all cases, would be 5 minutes)

3.3.3 Rainfall Intensity

Instead of using regional rainfall duration curves, TtEMI developed the relationship between rainfall intensity and Tc directly from data presented in the YEI report. Application of this relationship in the GIS serves a two-fold purpose: (1) as a data check, since a strong correlation between rainfall intensity and Tc indicates consistent application of rainfall intensity in YEI's calculations, and if a strong correlation exists, (2) ensures consistency of GIS results and YEI report estimates.

TtEMI developed a regression relationship between Tc and rainfall intensity using data from the YEI study for catchment C1 for 2-year and 5-year storm events (Figure B-6). The logarithmic plot of the data resulted in the best fit. A strong correlation exists between Tc and rainfall intensity (R^2 values greater than 98 percent for 2-year and 5-year rainfall intensity data). This correlation suggests the YEI study consistently applied regional rainfall duration curves.

The resulting procedure to estimate rainfall intensity from the adopted Tc uses the following equations:

$$I_2 = 6.5772 * T_c(\text{adopted})[minutes]^{-0.6459} \quad \text{(B-3)}$$

$$I_5 = 4.9944 * T_c(\text{adopted})[minutes]^{-0.4436} \quad \text{(B-4)}$$

where:

I_2	=	2-year Rainfall intensity (in/hr)
I_5	=	5-year Rainfall intensity (in/hr)
Tc	=	Time of concentration

4.0 SUMMARY

YEI evaluated the ability of the storm sewers to accommodate 2-year and 5-year storm events. YEI concluded, and TtEMI verified, that the existing system is generally capable of handling a 2-year storm event, whereas only portions are capable of handling discharge resulting from a 5-year storm event. In addition, TtEMI verified that calculations used by YEI generated conservative and reasonable peak-flow estimates for use in sediment-transport calculations. Therefore, it is not necessary to introduce a new set of flow estimates. TtEMI estimated actual peak flows for 2-year and 5-year events using the "Rational Method," which conservatively assumed that sewer hydraulics would not reduce flow.

Procedures outlined in this appendix allow for the transfer of YEI's procedures directly to GIS for use during the storm water flow evaluation. These procedures could be used for any storm sewer in the general area of HPS for 5-year storm events and catchments (less than 200 acres in size). Although the YEI procedures are valid for their original intended use, a more comprehensive hydraulic modeling approach should be developed to fully understand the transport of both liquids and solids through the storm sewer network.

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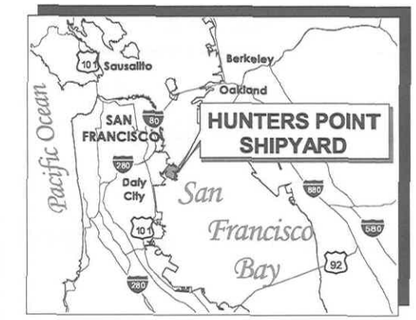


Location Map

Legend

- Storm Drain Outfalls
- Storm Drain Catch Basin
- Storm Drain Man Hole

Storm Drain Pipe Diameter

- 1 to 6 inch
- 6 to 16 inch
- 16 to 30 inch
- 30 to 60 inch
- Constructed Diversion
- C7 Catchment Identification Number
- Parcel A, B, C, D and E Boundary
- Parcel F Boundary
- Catchment Boundary
- Building

N

700 0 700

Scale in Feet

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

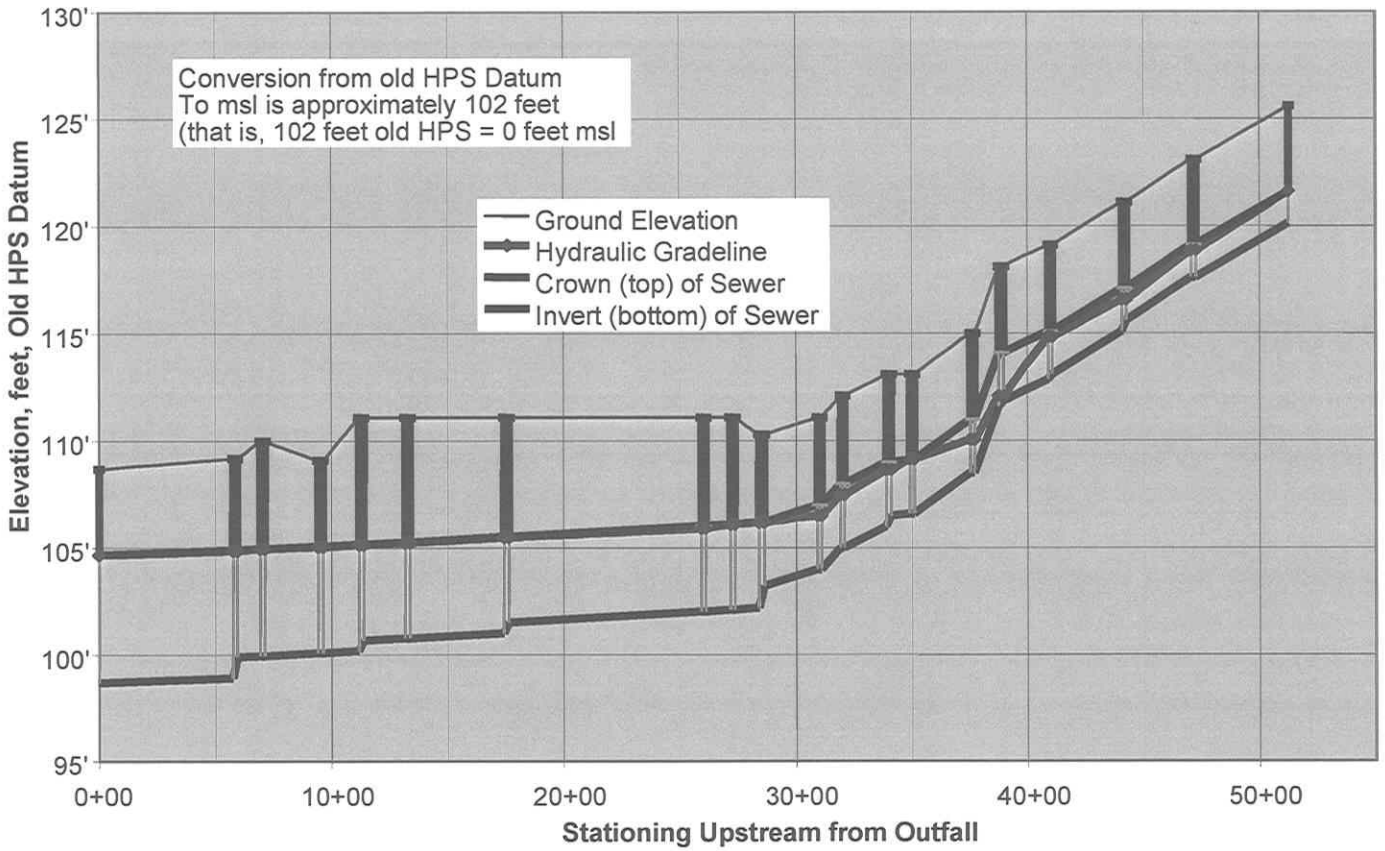
FIGURE B-1

STORM DRAIN SYSTEM

EVALUATION OF STORM WATER
AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

4/17/02 - O:\hunterfsed2\projects\report_figures.apr - KDC - Denver



Note:
msl Mean sea level

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

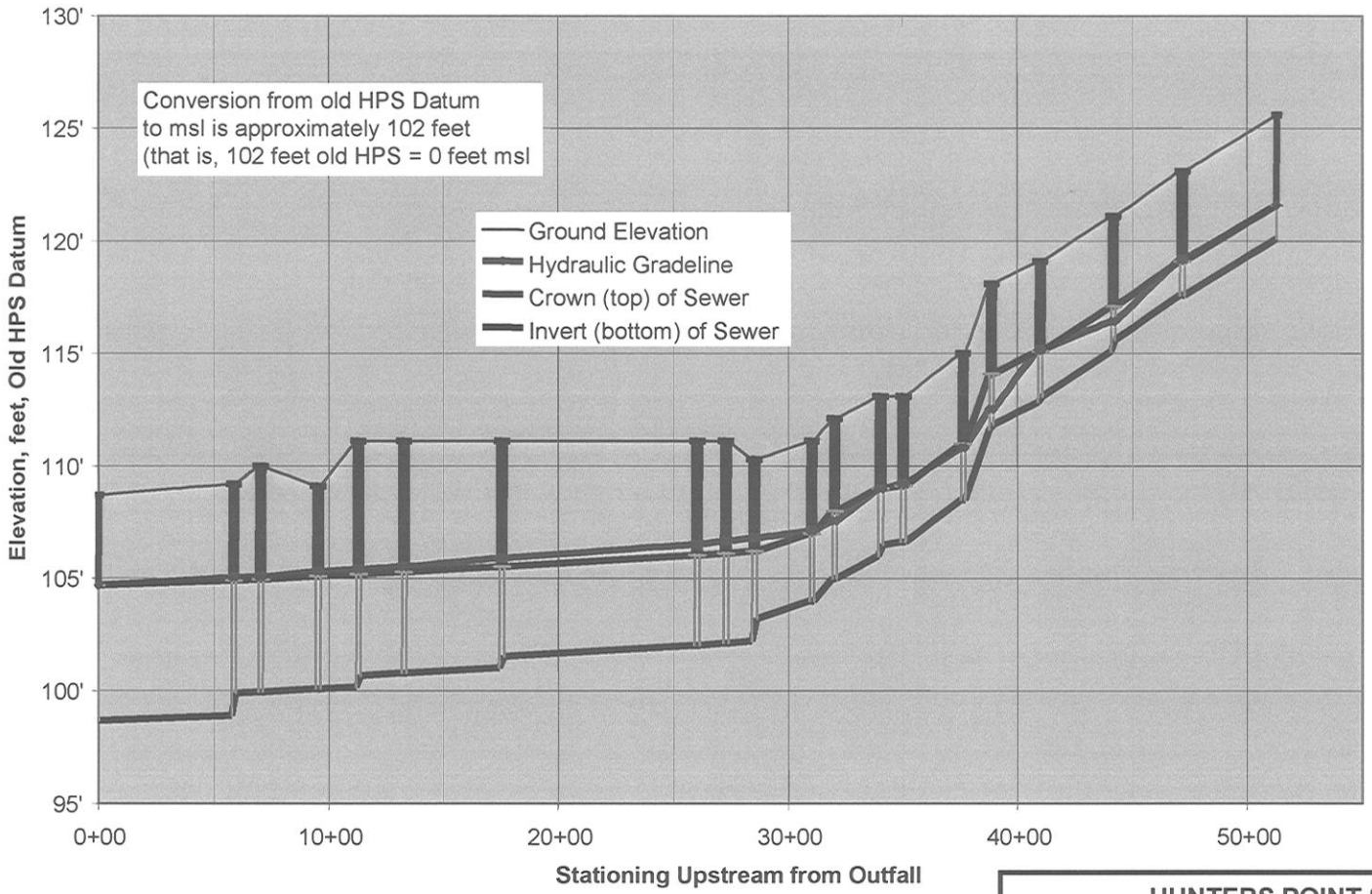
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE B-2

HYPOTHETICAL STORM SEWER AT 72-INCH OUTFALL FOR 2-YEAR STORM EVENT

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.



Note:
msl Mean sea level

HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

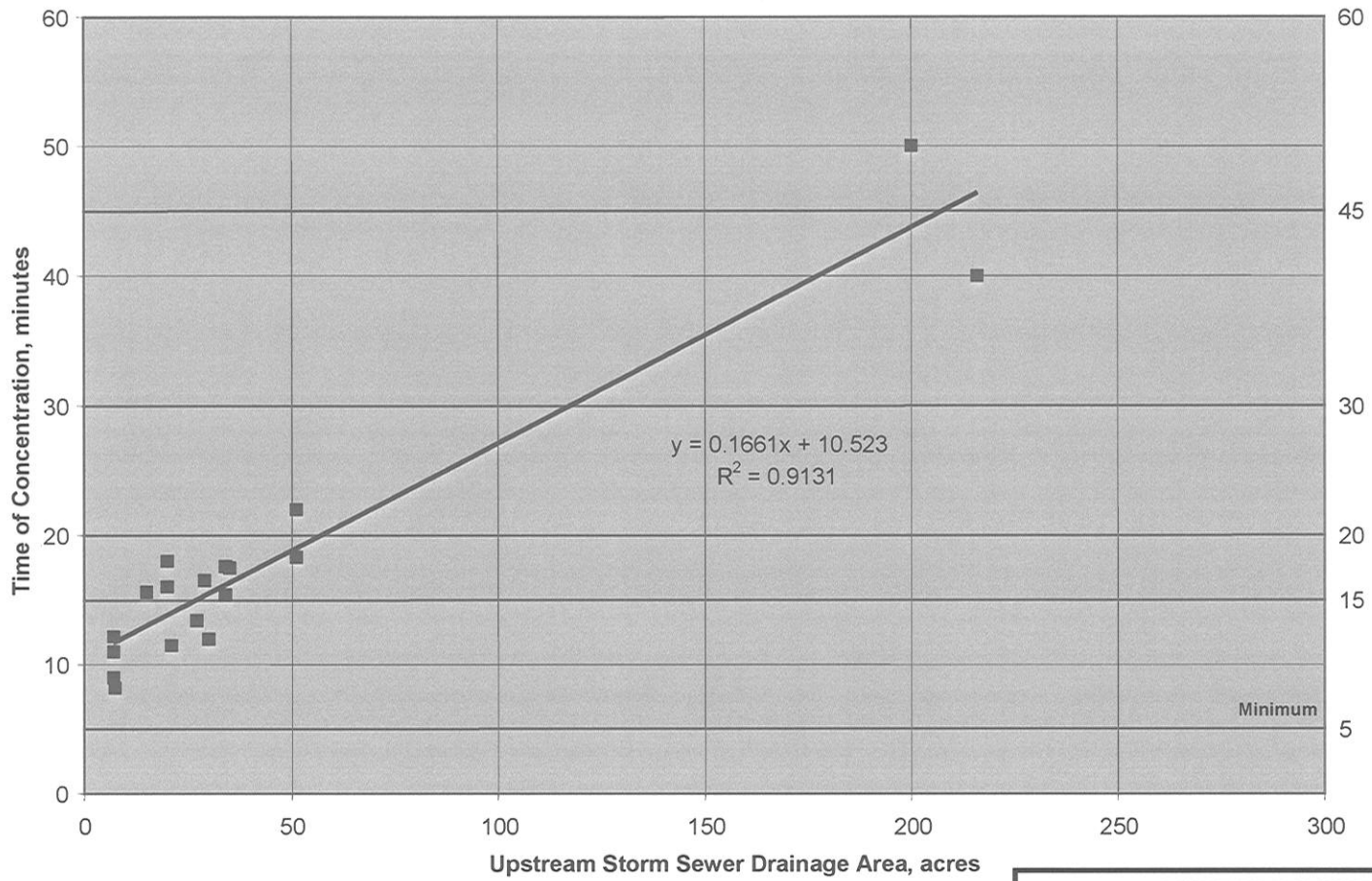
U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE B-3

HYPOTHETICAL STORM SEWER AT 72-INCH OUTFALL FOR 5-YEAR STORM EVENT

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.



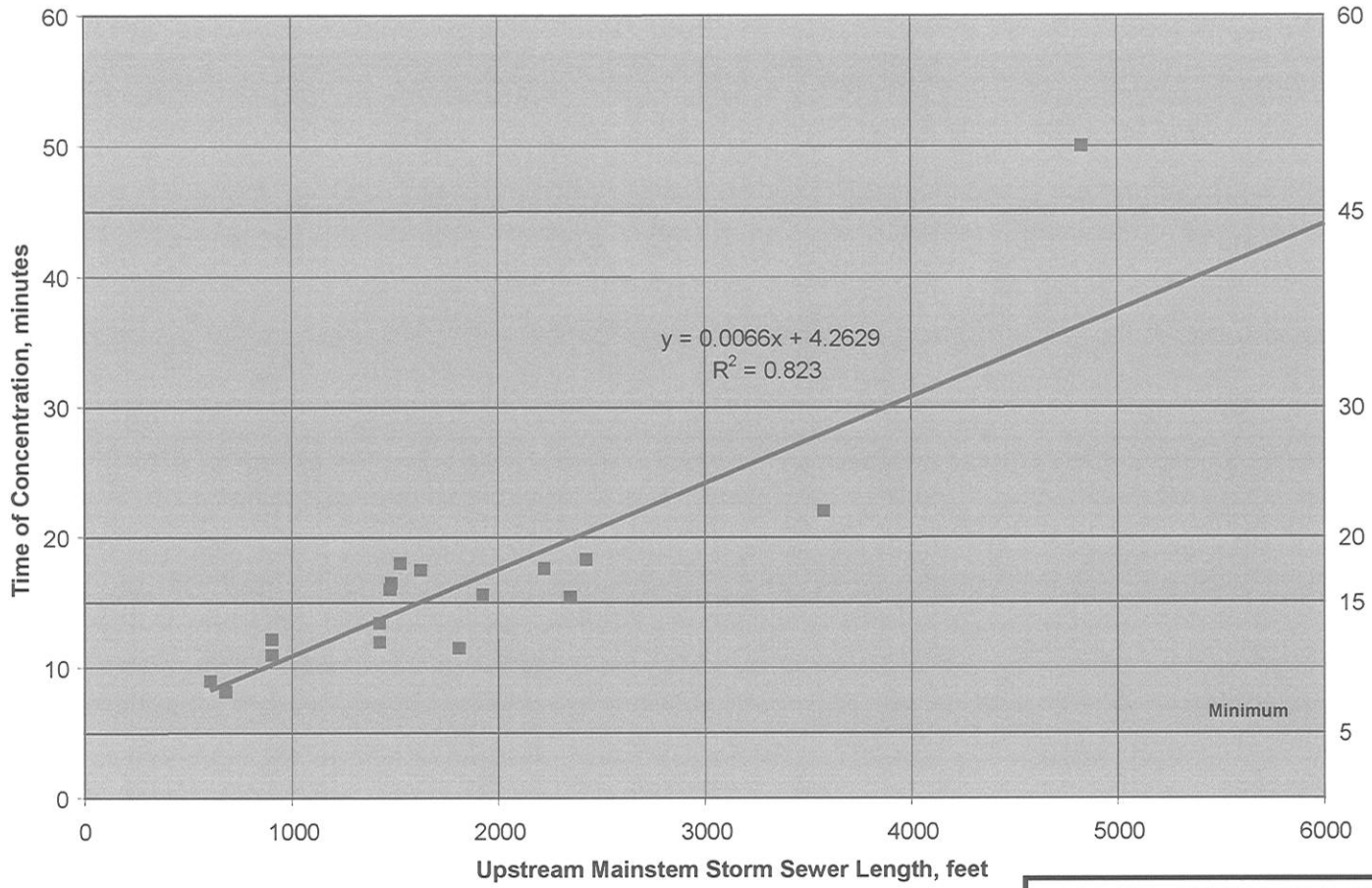
HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE B-4
TIME OF CONCENTRATION VERSUS UPSTREAM DRAINAGE AREA

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.



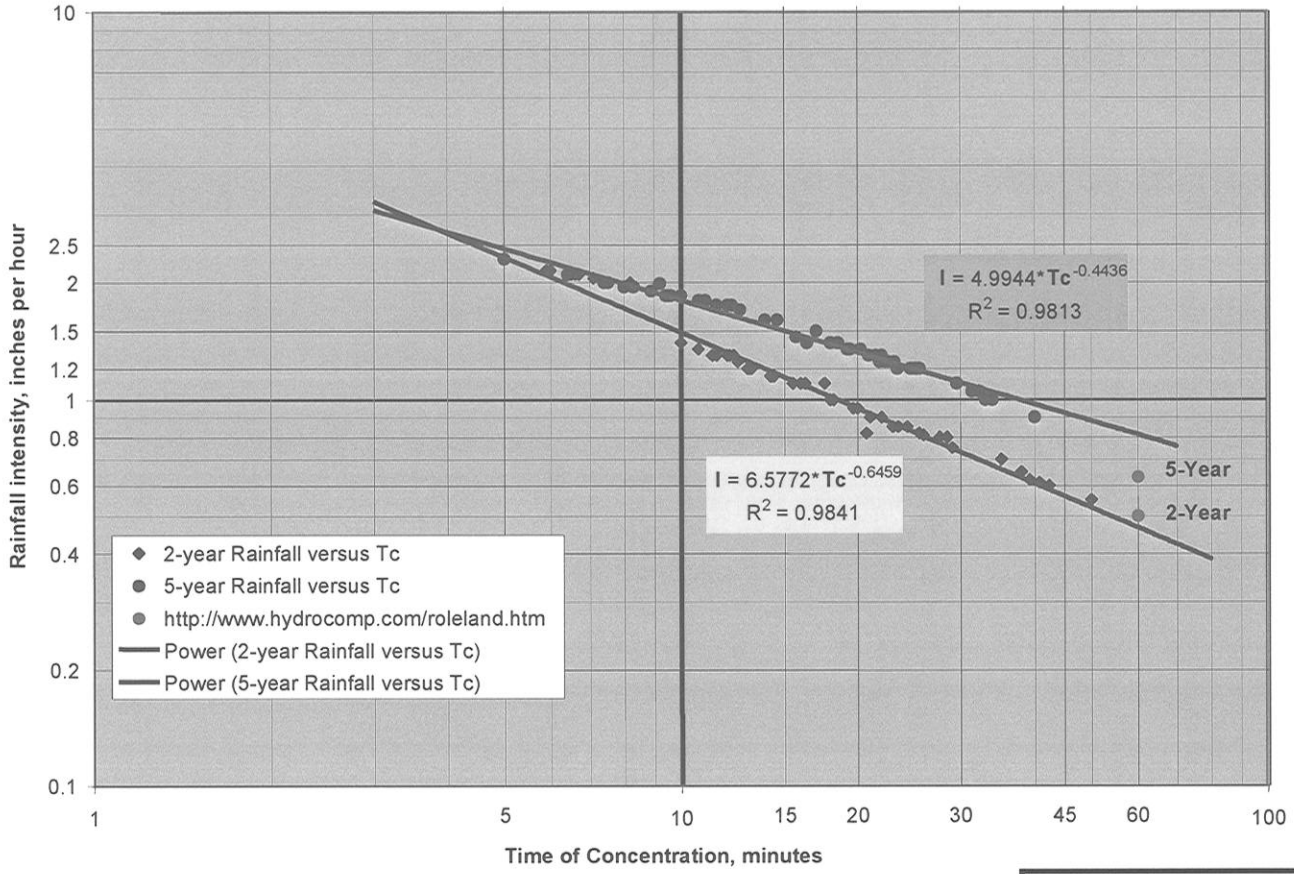
HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE B-5
TIME OF CONCENTRATION VERSUS UPSTREAM SEWER LENGTH

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.



HUNTERS POINT SHIPYARD
SAN FRANCISCO, CALIFORNIA

U.S. NAVY SOUTHWEST DIVISION NAVFAC, SAN DIEGO

FIGURE B-6
RAINFALL INTENSITY VERSUS TIME OF CONCENTRATION

EVALUATION OF STORM WATER AND SOLIDS DELIVERY TO PARCEL F

Tetra Tech EM Inc.

APPENDIX C

MODEL DESCRIPTION, ASSUMPTIONS, AND APPLICATION HUNTERS POINT SHIPYARD, SAN FRANCISCO, CALIFORNIA

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Attachment

C1 EXAMPLES OF "DISTURBED WEPP" AND "WEPP: ROAD" MODEL OUTPUTS

Figure

C-1 ILLUSTRATION OF THE OUTSLOPED/RUTTED OPTION

ABBREVIATIONS AND ACRONYMS

FSWEPP	Forest Service Water Erosion Prediction Project
Geo-WEPP	Geo-spatial interface for the WEPP model
GIS	Geographic information system
HPS	Hunters Point Shipyard
OFE	Overland flow element
RUSLE	Revised Universal Soil Loss Equation
TtEMI	Tetra Tech EM Inc.
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project

1.0 INTRODUCTION

Tetra Tech EM Inc. (TtEMI) evaluated the following erosion models for ease of use and ability to simulate site conditions at Hunters Point Shipyard (HPS), including climate, soil types, vegetation, topography, and land use:

- Revised Universal Soil Loss Equation (RUSLE) (Renard and others 1997)
- Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing 1995)

In addition, TtEMI evaluated the Forest Service WEPP (FSWEPP) interface and the Geo-spatial interface for the WEPP model (Geo-WEPP) (Renschler and others 2002).

After considering HPS site conditions and consulting with Elliot (TtEMI 2001), TtEMI selected the WEPP model and its FSWEPP interface as the most suitable for application at HPS. This appendix describes the models comparison, application of the FSWEPP model, and provides recommendations for further refinement of the model to obtain more robust predictions of erosion rates at HPS.

2.0 COMPARISON OF MODELS

Development of erosion models for soil and water conservation has a long history in U.S. research. The most common approach for estimating long-term average annual soil loss is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) or its successor, the RUSLE (Renard and others 1997). USLE and RUSLE are simple, empirical equations based on factors representing the main processes causing soil erosion. It should be noted that the RUSLE empirical model (U.S. Department of Agriculture 1997) does not use stochastic simulation for rainfall and runoff and does not include a hillslope sedimentation component. Therefore, results from this model may be less accurate than a model that follows similar methodology (such as WEPP). USLE and RUSLE have proven to be practical, accessible prediction tools. As a result, these equations were implemented in the U.S. soil and water conservation legislation (Renschler and others 2002). However, these equations have been widely used and misused to various degrees worldwide (Wischmeier 1976).

In contrast to the empirical model approaches, efforts in erosion process research in the U.S. helped to develop the WEPP model, a process-based hillslope soil erosion model (Flanagan and Nearing 1995). WEPP simulates climate, infiltration, water balance, plant growth and residue decomposition, tillage, and consolidation to predict surface runoff, soil loss, deposition, and sediment delivery over a range of time, including individual storm events, monthly totals, yearly totals, or an average annual value based on data

for several decades (Renschler and others 2002). The WEPP model is a continuous, distributed-parameter soil erosion assessment tool that can be applied to representative hillslopes and a channel network at small watershed scales (Ascough II and others 1997). A comparison of WEPP performance with other state-of-the-art erosion models using common data sets showed that data quality is an important consideration and process-based models that do not require calibration have a competitive edge over those models that need calibration (Boardman and Favis-Mortlock 1998).

TtEMI considered two interfaces for the WEPP model for application at HPS: FSWEPP and Geo-WEPP. TtEMI found Geo-WEPP to be too sophisticated and time consuming for use in obtaining preliminary estimates of mean annual erosion at HPS. Therefore, TtEMI selected the FSWEPP interface as the most suitable model for use at HPS (TtEMI 2001).

The FSWEPP model is a U.S. Forest Service Internet-based application of WEPP (Elliot and others 1999, 2000) that allows the user to specify the following:

- Climate
- Soil
- Topography
- Flow path length
- Road design and surface condition
- Ditch condition
- Vegetative cover
- Time period

These inputs are entered in the FSWEPP model to determine mean annual average erosion rates. The FSWEPP model estimates average annual erosion and generates a stochastic prediction for the selected climate and number of years specified by the modeler. In addition, the FSWEPP model runs a daily simulation for the specified time period and calculates average annual runoff, erosion, and sediment yield values. For each day that has a precipitation event, the FSWEPP model calculates infiltration and runoff. If there is runoff, FSWEPP routes the runoff over the surface, calculating erosion or deposition rates for at least 100 points on the hillslope. The model then calculates the average sediment yield from the hillslope (Elliot and others 2000). Attachment C1 provides examples of these calculations.

Another feature that makes the FSWEPP model appropriate for HPS site conditions is: the model allows a hillslope to be divided into segments with similar site characteristics (or overland flow elements [OFE]).

Combinations of these OFEs are applied to simulate conditions that represent different manmade disturbances that, in turn, affect erosion and sedimentation processes.

3.0 MODEL APPLICATION

This section describes the assumptions that must be considered due to the limitations of the model and available information, including the modules used and specific inputs used to adapt the FSWEPP model to HPS site conditions.

3.1 FSWEPP MODULES

The FSWEPP model has various interfaces, allowing it to adapt to situations that could be encountered in different environments. TtEMI determined that the "Disturbed WEPP" and "WEPP: Road" modules would be suitable for predicting erosion at HPS (TtEMI 2001). "Disturbed WEPP" was used for catchments C11 and C12 that are predominantly noncompacted surfaces without storm sewer outlets and for the vegetated, steeper portions of catchments C1 through C10. Whereas, "WEPP: Road" was adapted for the compacted surfaces of catchments C1 through C10.

"Disturbed WEPP" is designed to predict runoff and sediment yield from lands that are not highly compacted (Elliot and others 2000), for example:

- Young and old undisturbed forests
- Prescribed and wild forest fires
- Skid trails and harvested forests
- Rangelands with short grass, tall grass, and shrub plant communities
- Parks, pastures, or any land with little soil disturbance (no tillage) but a definable amount of soil residue cover

However, "Disturbed WEPP" is not intended for sites where soil is severely disturbed or compacted such as roads and trails, construction sites, or heavily used playgrounds. For such conditions, "WEPP: Road: was used because it is designed to predict runoff and sediment yield from the following (Elliot and others 1999):

- Roads
- Compacted landings
- Compacted skid trails
- Compacted foot or off-road vehicle trails

In addition, to further detail the input, each of the 12 catchments can be subdivided into areas of uniform conditions (represented by the appropriate OFEs) that affect erosion and sedimentation processes.

The "Disturbed WEPP" template allows the catchment area to be divided into two OFEs (upper and lower hillslopes, respectively). The following inputs are required to run this module:

- Slope: The average slope gradients for each element (upper and lower hillslope) were applied.
- Soil type: The module was run separately for two soil types (sand and silt) that are representative of the surface soil textures at HPS.
- Vegetation cover: Short prairie grass was selected as the representative vegetation cover.
- Mean flow path length: Calculated by geographic information system (GIS) spatial analyst (see Figure 9 in the main text).
- Acreage: Specific to each applicable area within the catchment modeled.
- Percent vegetative cover: Specific to each applicable area within the catchment modeled.

"WEPP: Road" uses three OFEs to represent various conditions on compacted surfaces: a road area, a hillslope, and a buffer. The following inputs are required to run this module:

- Slope: A slope gradient was specified for each element (road, fill, and buffer).
- Soil type: The module was run separately for two soil types (sand and silt) that are representative of the surface soil textures at HPS.
- Mean flow path length: Calculated by GIS spatial analyst.
- Road design: The "Outsloped, Rutted" option was chosen to describe the road structure for the applicable areas.
- Road width: This value was set at 100 feet as a representative width of most roads at HPS.
- Road surface: The road surface is more accurately represented by the "graveled" category because on-site asphalt is considerably degraded and the surface is littered.

3.2 ASSUMPTIONS AND APPLICATION RULES

In order to use the information and modules discussed above as efficiently and accurately as possible, certain guideline rules and general assumptions had to be established.

3.2.1 Assumptions

The modeling used the following assumptions:

1. Catchments C1 through C12 are composed of erosive surfaces that may be characterized by representative OFE for each catchment slope class.

2. All potentially eroded material (100 percent) from catchments C1 through C10 is predicted to be delivered solids without attenuation by a vegetated buffer. Solids delivered to the storm sewers in catchments C1 through C10 are immediately delivered to Parcel F. Similarly, solids delivered to the interface between the land portion of catchments C11 and C12 and Parcel F are also considered to be delivered to Parcel F.

3. Catchments C1 through C10:

   - Areas where the slope is less than or equal to 20 percent were considered compacted due to pavement, construction, buildings, vehicle rails, and so on. "WEPP Road" is the suitable module for these areas.

   - Areas where the slope is greater than 20 percent are considered to be vegetated by short grass and some trees. Because of the slope steepness and the location of these steeper slopes, it is not likely that construction or other activities compacted the area. "Disturbed WEPP" is the suitable module for these areas.

4. "Disturbed WEPP" is the suitable model for catchments C11 and C12, since they are generally not compacted.

5. Deposition of eroded materials will occur on HPS on concave or flat surfaces that occupy 89 percent of the total area of HPS (Figure 7 of the main document). However, to provide a conservative estimate of erosion at HPS, predicted erosion quantities are projected as sedimentation quantities for the highly compacted and paved surfaces of catchments C1 through C10. The "WEPP Road" fill and buffer, which constitute depositional areas, were therefore reduced to the minimum widths that could be used by the model to provide a conservatively higher predicted erosion rates.

6. Steep slopes on the south side of Parcel E and the north side of catchment C12 are covered in various sorts of riprap, which aid in retaining the soil. Therefore, these slopes were not considered to be erosive surfaces.

7. To compare predicted erosion from HPS catchments with sediment accretion in the pier areas (see Figure 4 in the main document), TtEMI delineated two subcatchments (C1A and C1B) that are in catchment C1. TtEMI assumed that solids delivery from subcatchments C1A and C1B was along Berths 29 and 23, respectively. "WEPP Road" is the suitable module for each subcatchment (see also Section 4.4 of the main document).

3.2.2 Application Rules

The application rules below were used to model erosion and sedimentation at the 12 catchments.

1. Both "Disturbed WEPP" and "WEPP Road" modules used climate data for San Francisco and were run for a 50-year return period. Using a 50-year return period results in conservatively higher predicted erosion rates than using a shorter return period.

2. "WEPP Road" module used "outsloped, rutted" option to minimize the effect of outsloping on overland flow. The figure below illustrates this option. The resulting predicted erosion rates are conservatively higher than if "outsloped, unrutted" is used.

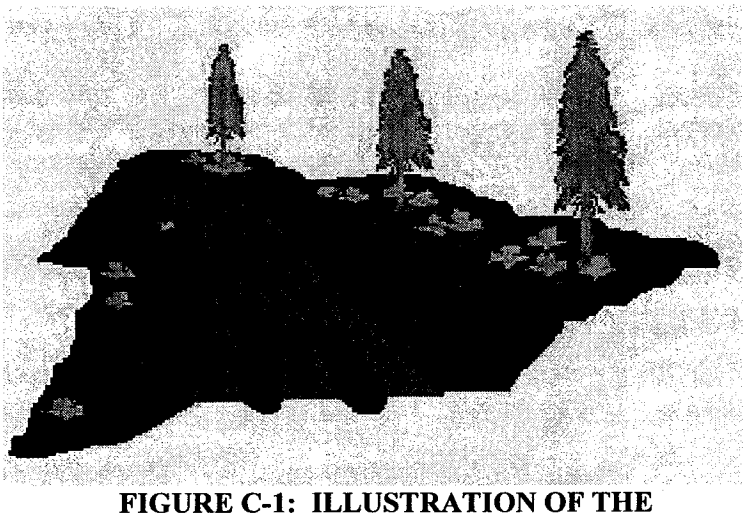

FIGURE C-1: ILLUSTRATION OF THE OUTSLOPED/RUTTED OPTION

3. For each individual catchment, the weighted average erosion rates are calculated for each slope steepness class as follows:

   (Slope Class Area * Erosion Rate for Slope Class)/(Total Catchment Area)

   The erosion rates estimates are adjusted for each slope class by subtracting the paved area from the slope class total area:

   ((Erosion Rate for Slope Class)*(Slope Class Area - (Slope Class Area * Percent Paved for Slope Class Area)))/(Total Catchment Area)

   The resulting erosion rates estimates for each slope class are then averaged to obtain an erosion rate for a catchment as a whole.

4. Catchment C11 was modeled using two areas with similar sets of OFEs that had a low grass vegetation cover (40-percent level), and the results were summed.

5. Catchment C12 was modeled as a single area with the same OFE and a land vegetation cover of 15 percent.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The FSWEPP model has proven to be a valuable and effective tool for obtaining preliminary and conservative estimates of soil erosion at HPS. Further refinement of the WEPP model application to obtain more robust erosion predictions requires using a more sophisticated interface such as Geo-WEPP. Using the Geo-WEPP interface will help integrate geo-referenced information available in HPS GIS and prepare valid model input parameters. In addition, the fully integrated "HPS GIS – Geo-WEPP" system will enable effective sensitivity analyses of model predictions for any site-specific assessments of solids delivery to Parcel F.

5.0 REFERENCES

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ATTACHMENT C1

EXAMPLES OF "DISTURBED WEPP" AND "WEPP: ROAD" MODEL OUTPUTS

USER INPUTS

(This screen summarizes the initial inputs entered)

Location	SAN FRANCISCO WB CT CA				
Soil texture	sandy loam				
Element	Treatment	Gradient (%)	Length (ft)	Area (ac)	Cover (%)
Upper	short prairie grass	15 32.5	80.8	41.63	20
Lower	short prairie grass	32.5 15	80.8		20
	Width (ft)		11220.59		

MEAN ANNUAL AVERAGES FOR 50 YEARS

20.90	in.	precipitation from	3330	storms
1.43	in.	runoff from rainfall from	250	events
0.00	in.	runoff from snowmelt or winter rainstorm from	0	events
8.18	t ac^{-1}	upland erosion rate (1.839 kg/m^2) **		
8.18	t ac^{-1}	sediment leaving profile (90.58 kg/m width)		

** *This line reports the value used to further calculate erosion rate for a catchment as a whole.*

RETURN PERIOD ANALYSIS BASED ON 50 YEARS

Return Period	Precipitation (in.)	Runoff (in.)	Erosion (t ac^{-1})	Sediment (t ac^{-1})
50 year	29.64	4.74	24.31	24.31
25 year	29.62	4.54	23.61	23.60
10 year	26.32	2.84	15.94	15.93
5 year	25.29	2.29	13.41	13.41
2.5 year	22.49	1.50	8.73	8.73
Average	20.90	1.43	8.18	8.18

YEARLY PROBABILITIES BASED ON 50 YEARS

Probability there is runoff	100 %	
Probability there is erosion	100 %	
Probability of sediment delivery	100 %	

(Note: Extended Output not included)

WEPP:ROAD RESULTS

INPUTS					
SAN FRANCISCO WB CT CA			Gradient (%)	Length (ft)	Width (ft)
Outsloped, rutted		Road	3	63.9	100
sandy loam		Fill	3	1	
graveled surface		Buffer	3	1	

50 - YEAR MEAN ANNUAL AVERAGES

20.89	in	precipitation from	3330	storms
3.72	in	runoff from rainfall from	900	events
0.00	in	runoff from snowmelt or winter rainstorm from	0	events
1587.80	lb	road prism erosion		
1251.39	lb	sediment leaving buffer		

Initial inputs are summarized and the resulting 50-year mean annual average outputs are indicated.

WEPP OUTPUT

(NOTE: The following text presents the extended output results)

Annual; abbreviated (Metric Units)

```
USDA WATER EROSION PREDICTION PROJECT
-------------------------------------

HILLSLOPE PROFILE AND WATERSHED MODEL
      VERSION  2000.100
  June 31,     2000


   TO REPORT PROBLEMS OR TO BE PUT ON THE MAILING
   LIST FOR FUTURE WEPP MODEL RELEASES, PLEASE CONTACT:

      WEPP TECHNICAL SUPPORT
      USDA-AGRICULTURAL RESEARCH SERVICE
      NATIONAL SOIL EROSION RESEARCH LABORATORY
      1196 BUILDING SOIL, PURDUE UNIVERSITY
      WEST LAFAYETTE, IN 47907-1196  USA

      PHONE: (765) 494-8673
       FAX: (765) 494-5948
      email:  wepp@ecn.purdue.edu
       URL:  http://topsoil.nserl.purdue.edu/weppmain/wepp.html

HILLSLOPE INPUT DATA FILES - VERSION 2000.100
    June 31, 2000
```

Input Files built by WEPP:Road based on user specifications.

MANAGEMENT: data/3outrut.man
MAN. PRACTICE: Road Section for water to follow ruts, and release over
fill-slope to a forest for deposition
W. Elliot & H. Rhee 1/99 USDA Forest Service
SLOPE: ../working/wepp-26730.slp
CLIMATE: ../working/wepp-26730.cli
Station: SAN FRANCISCO WB CT CA CLIGEN VERSION 4.31
SOIL: data/3gsand2.sol
PLANE 1 Road sandy loam
PLANE 2 Fill sandy loam
PLANE 3 Forest sandy loam

Total and Average Annual summaries of Precipitation and Runoff.

ANNUAL AVERAGE SUMMARIES

I. RAINFALL AND RUNOFF SUMMARY
--- --- --- ---

total summary: years 1 - 50

3330 storms produced	26528.24 mm of precipitation
900 rain storm runoff events produced	4724.71 mm of runoff
0 snow melts and/or events during winter produced	0.00 mm of runoff

annual averages

Number of years	50
Mean annual precipitation	530.56 mm
Mean annual runoff from rainfall	94.49 mm
Mean annual runoff from snow melt and/or rain storm during winter	0.00 mm

Total and Average Annual Summaries of Distribution of Erosion and Deposition.

II. ON SITE EFFECTS ON SITE EFFECTS ON SITE EFFECTS
--- --- ---

A. AREA OF NET SOIL LOSS

** Soil Loss (Avg. of Net Detachment Areas) = 1.213 kg/m2 **
** Maximum Soil Loss = 1.619 kg/m2 at 19.48 meters **

➔ *The Maximum Soil Loss line reports the value used in further calculations of erosion rate for a catchment as a whole.*

(Note: Rest of extended output results not included)