INCORPORATING THE CONCEPT OF RISK IN STORMWATER MANAGEMENT

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ABSTRACT

Stormwater runoff has been identified as a major source of pollution to Tampa Bay. This led SWFWMD to the development of a water quality management plan to control and reduce pollutant loading from the McKay Bay watershed. Traditionally, water quality management plans have been developed using approaches that lend little consideration to the relative risk associated with those contaminants. In addition, the identification of the type of treatment required for both baseflow and stormwater runoff has been done based on generalizations of water quality conditions in the incoming flows. This paper discusses the application of a risk-based approach for identifying pollutants of concern in the McKay Bay watershed, as well as the methodology used for identifying pollution control methods.

INTRODUCTION

Previous studies have demonstrated that concentrations of contaminants in water, sediment, and biota in Tampa Bay are elevated and in certain areas exceed regulatory or guidance levels designed to protect ecological resources (Brooks and Doyle 1992; Long et al 1991, 1994) and/or human health (Frithsen et al, 1995 and Parson ES 1996). One of the most important areas of concern is McKay Bay, the 1,400-acre urban estuary located on the northeast portion of Tampa Bay.

As part of the effort to control pollution in Tampa Bay, SWFWMD elected to conduct a water quality management study of the McKay Bay watershed. This watershed is an intensely urbanized area covering approximately 30-square mile area that collects predominantly untreated stormwater from concentrated industrial areas and residential developments. An important source of the pollution load entering McKay Bay is from stormwater runoff. Pollution impacts in the Bay have involved changes in the chemical, physical, and/or biological integrity of the system. In addition, impacts may include increased risk to human health with exposure to toxic pollutants through ingestion of fish or shellfish.

The overall objectives for the water quality management plan were to identify, analyze, and recommend control measures to control pollutants. A general risk-based framework was used to meet these objectives. To optimize the removal efficiency of potential control measures, it was necessary to first identify chemicals of potential concern (COPCs). Previous studies have identified control of nitrogen loads as a major water quality objective for the entire Tampa Bay. Other COPCs considered in this study were those chemicals that may cause adverse (toxic) effects in aquatic or terrestrial organisms, or that pose potential human health risks. A preliminary risk analysis was used to identify the COPCs and prioritize discharge locations for further study. The methodology and results used for identification of COPCs and basin prioritization based on contaminant risks versus total loads have been presented previously.

Based on the results of preliminary analysis, a limited baseflow, stormwater, and sediment sampling program was implemented to further characterize stormwater discharges. The results of this sampling effort were then used to develop appropriate measures to decrease pollutant loads and reduce risks associated with nonpoint discharges of COPCs. Typical stormwater management projects focus on total loads of conventional parameters like nutrients and metals, and recommend treatment methods on removal of particulates. VA-Ale traditional methods may be adequate for reduction of pollutant loads, the results of this study suggest that additional consideration of pollutant form is required to address potential risks associated with stormwater pollutants. The sampling results for this study suggest that for both baseflow and stormwater discharges, the dissolved fraction of numerous stormwater pollutants represented a significant portion of the total discharge, and should be considered when selecting appropriate treatment methods. The methods and results for the baseflow and stormwater sampling plan and subsequent development of BMPs to reduce pollutant loadings are discussed in this paper. Sediment sampling results are also discussed briefly as they relate to stormwater discharges.

Methodology

For the McKay Bay study, baseflow, stormwater, and sediment samples were collected from strategic locations within the watershed on the preliminary risk evaluation of historical water and sediment quality data. Baseflow and sediment sampling were performed in June 1997; wet weather sampling was performed in December 1997 and January 1998. All field and laboratory measurements were performed in accordance with the FDEP/EPA approved Comprehensive Quality Assurance Project Plan.

A total of five baseflow grab samples were collected at the end of the dry season. One field duplicate and one equipment blank were also collected. Samples were collected at stations located in the lower to middle portions of three drainage basins considered the highest priority for pollutant control purposes, the 29th St., 43' St. and 50' St. basins.

Stormwater samples were collected near the outfalls of two of the priority basins, the 291 St. and 501 St. drainage basins. Flow-weighted composite samples were collected for representative storm events at each sampling location (total of two sampling events). Rainfall data prior to and during storm sampling events were also evaluated as part of the stormwater sampling plan to estimate rainfall versus runoff relationships. General criteria for qualifying rain events were set in accordance with U.S. EPA criteria: the range of acceptable rainfall events was set at 0.24 to 0.71 inches, a minimum of three hours of rainfall had to fall within this range, a minimum of three hours of rainfall had to occur, and qualifying storm events had to be preceded by 72 hours of dry weather. Some deviation was allowed on the high end of the rainfall range as long as it fell after the first three hours.

In addition to baseflow and stormwater data, limited sediment data were collected in depositional areas to help identify critical outfalls/discharges that represent potential sources of COPCs. These data will also be used for future comparisons to evaluate the effectiveness of implemented management practices. A total of seven surficial sediment grab samples were collected from the following areas: Northern McKay Bay adjacent to the 29th-50th Street outfalls, southeast McKay Bay adjacent to the SWFWMD parcel, northwest McKay Bay near DeSoto Park, and two Palm River stations near the US41 bridge and at the confluence with McKay Bay.

The following parameters were included in the sampling plan: oil and grease (O&G), total petroleum hydrocarbons (TPH), polyaromatic hydrocarbons (PAHs), pesticides (organochlorine/phosphate insecticides and herbicides), metals (cadmium, chromium, copper, lead, mercury, and zinc; total and dissolved), ammonia, nutrients (nitrate/nitrite, total nitrogen, ortho- and total phosphorous), total and dissolved solids, and BOD5. For the stormwater samples, TPH was analyzed instead of oil and grease; for sediment samples, individual PAHs were analyzed instead of O&G or TPH. Field measurements included temperature, specific conductance, pH, DO, and ORP at each sample location. One equipment blank was collected per sampling event. Water sample analyses were performed by several certified laboratories including the Southwest Florida Water Management District (SWFWMD), Environmental Quality Laboratory (EQL), and Southern Analytical Laboratories. Sediment sample analyses were performed by several certified contract laboratories including EQL and Savannah Laboratories.

RESULTS

Analytes detected in the baseflow (6/97) and wet weather (12/97 and 1/98) sampling are summarized in Table 1. Sediment sampling results are not tabulated in this paper, but are discussed briefly as they relate to stormwater discharges. Conventional parameters measured included: ammonia, and nutrients (nitrate/nitrite and phosphorous), solids (total and suspended), and BOD,. Toxic pollutants detected in baseflow and/or stormwater included: organic chemicals (TPH, phthalates, foaming agents, bis(2-chloroethyl-ether, malathion, and pentachlorophenol), and 11 metals (arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc).

Toxic pollutants detected in sediment samples included PAHs and metals. Several classes of organic
chemicals (i.e., organochlorine/phosphate insecticides and herbicides) were included in the sampling
plan due suspected discharges from land uses within the watershed and/or historical sediment and stormwater data. With the exception of malathion, pesticides were not detected in baseflow, stormwater, or sediment samples collected for this project. This may reflect elevated laboratory detection limits that did not allow detection of contaminants present at very low concentrations.

Nutrients

No numeric water quality criteria exist for nutrients and BOD as impacts depend on the specific characteristics of each water system. However, the water quality in tributaries discharging to McKay Bay is above the 80" percentile compared to other Florida streams based on total nitrogen concentration.

Table 1

Baseflow and Stormwater Data
McKay Bay Water Quality Management Plan

		43rd St.		29th St.Basin				50th St. Basin				FL WOC'	
		Baseflow		Baseflow		Stormwater		Baseflow	Stormwater				
Analyte	Units	Sta3	Dup(St.7)	Sta1	Sta2	S11-12/97	S11-1/98	Sta4	Sta5	S12-12/97	S12-1/98	Fresh	Marine
Conventional Parameters													
Ammonia	mg/l as N	0.02	0.03	0.08	0.06	0.66	0.02	0.41	0.16	< 0.01	0.21	:5 0.02	
Nitrate + Nitrite	mg/l as N	0.01	0.02	0.93	1.23	0.80	0.40	1.82	0.51	0.48	0.49	No population imbalance.	
TKN (NH3+Org N)	mg/ as N	1.28	1.61	0.60	0.42	NA	NA	1.64	1.29	NA	NA	No population imbalance.	
Nitrogen, total	mg/l as N					2.20	0.91			0.87	1.70		
Phosphorous, ortho	mg/l	0.62	0.63	0. t7	0.15	0.66	0.20	0.56	0.51	0.18 1	0.48	No population imbalance.	
Phosphorous, total	mg/l as P	0.75	0.76	0.18	0.15	0.72	0.28	0.59	0.59	0.25	0.61	No population imbalance.	
Dissolved Solids, total	m	14	307	2055	492	281	12	709	2529	179	230		
Suspended Solids, total	mg/l	2.24	214	0.43	0.35	32.06	12.04	0.52	6.03	31.24	18.45		
BOD	mg/l	3.8	4.9	<1	<1	7.3	15.4	1.8	1.2	7.3	59.5	No diss.oxygen impact.	
Organic Chemicals													
Oil and Grease	mg/l	< I	< 1.0	< 1.00	< 1.00	NA	NA	< 1.00	< 1.00	NA	NA	<=5.0	<=5
TPH*	mg/I	NA	NA	NA	NA	243	113	NA	NA	318	< 100		
Foaming Agents	mg/I LAS	2.20	2.30	0.22	0.12	NA	NA	0.17	0.42	NA	NA	<= 0.5	<= 0.5
Malathion	mg/I	8.5	6.2	11	5	< 1.0	< 1.0	< 1	< 1	< 1.0	<1.0	<= 0.1	<=0.1
Butyl benzyl phthalate	mg/I	< I	< 1.0	1.1	< I	< 1.0	< 1.0	< 1	< 1	< 1.0	1.4	<=3	
Di(2-dhylhexyl)phthalate	Mg/l	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	30.6			< 1.0	1.2	<=3	
Bis(2-chloroethyl) ether	mg/l	1.6	140.0	< 1	< 1	< 1.0	< 1.0	< 1	<1	< 1.0	< 1.0		
Pentachlorophenol	Mg/l	< 1-0	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0			0.13	< 1.0	<= 30.0	<= 7.9
Metals													
Arsenic, total	Mg/I	NR	NR	NR	NR	< 23	< 23	NR	NR	< 23	< 23	<=50.0	<= 50
Arsenic dissolved	Mg/l	15.7	13.4	1.3	0.9	6.9	1.92	13.2	0	0.959	6.87		<= 36
Cadmium, total	mg/I	< 0.3	< 0.3	< 0.3	<0.30	.997	2.35	< 0.3	< 0.3	0.692	2.08	<=0.4	<=9.3
Cadmium dissolved	Mg',	0	0	0	0	0.41	0.312	0.1	0	0.24	0		
Chromium, total	mg/l	< 4.7	< 4.7	< 4.7	< 4.7	10.9	< 4.7	< 4.7	< 4.7	5.99	< 4.7	<=67	
Chromium dissolved	Mg/l	2.1	1.9	0.8	0	4.44	0.351	1.2	0.9	2.01	0.536	<= 11.0	<=50
Copper, total*	Mg/I	11.1	12.1	1.8	< 1	55.1	10.2	11.6	6.1	23.3	34.3	<= 3.6	<=2.9
Copper, dissolved	Mg/I	6.6	6.6	1.3	0	21.5	9.75	7	1.9	7.75	8.99		

Table 1, cont.
Baseflow and Stormwater Data
McKay Bay Water Quality Management Plan

		43rd St.		29th St.Basin				50th St. Basin				FL WQC	
		Baseflow		Baseflow		Stormwater		Baseflow		Stormwater			
Analyte	Units	Sta3	Dup (Sta7)	Sta.1	Sta2	S11-12/97	S11-1/98	Sta4	Sta5	S12-12197	S12-1/98	Fresh	Marine
Metals, cont.													
Iron, total	mg/l	0.344	0.311	0.320	0.329	2.38	0.32	0.281	0.406	1.54	0.73	<= 1.0	<= 0.3
Iron, dissolved	mg/l	0.199	0.2	0.045	0.022	1.00	0.30	0.192	0.161	0.59	0.63		
Lead, total*	Ug/l	2.8	< 2	< 2	2.9	24.83	4.59	3.4	5.6	22.96	10.6	<=0.54	<= 5.6
Lead, dissolved	Ug/l	1.4	0	0.6	3	9.2	2.77	1.9	0.7	10.5	6.59		
Mercury, total*	Ug/l	< 0.1	< 0.1	< 0.1	< 0.1	0.3	0.17	< 0.1	< 0.1	0.42	0.115	<= 0.012	<=0.025
Mercury dissolved						< 0.1	0.12			0.12	0.13		
Nickel, total	Ug/I	52.7	59.6	< 4.3	< 4.3	10.6	< 4.3	< 4.3	< 4.3	5.22	4.59	<= 48.8	<= 8.3
Nickel, dissolved	Ug/l	46.2	68.0	0	3.5	3.45	1.45	2.3	1.8	1.28	3.07		
Zinc, total*	ug/l	< 30	<30	<30	<30	181	46.3	30	42	160	83	<=32.7	<=86
Zinc, dissolved	ug/l	36	40.0	14	10 75.8	43.5	42	29 59.6	62.1				

Note:
"*"- indicates CON (see text).
NR-not reported; NA- not applicable, "0" -value as reported by SWFWMD analytical lab.
Baseflow grab samples collected 7/97 and stormwater samples collected 12/97 and 1/98.
1. Florida water quality criteria (WQC), Class III, from 62-302.530, 1/96. Blank indicates no criterion.
Freshwater metals criteria for Cd, Cr, Cu, Pb, Ni, and Zn based on default hardness of 25 mg/l.
Criterion for As based on As+3, total chromium based on Cr+-3, dissolved Cr based on Cr+6.
Criterion for foaming agents (LAS) based on detergents, butyl benzyl phthalate based on total phthalates.

As shown in Table 1, the concentration of total nitrogen was relatively constant. In five out of the six samples it varied between 1.3 and 1.8 mg/L. However, the concentration of the various forms of nitrogen varies widely among stations. For example, the ratio of NOx to total nitrogen varies between 0. 0 1 and 0.75. The limited nature of the sampling program did not allow for an analysis of causes for this condition.

Stormwater samples show a larger variation in the concentration of total nitrogen than baseflow samples, with values ranging from 0.87 and 2.20 mg/L. In addition, the data do not show consistency among the two stations sampled. The sample from the first storm event showed that the total nitrogen concentration in the 29' St. basin was approximately twice as large as the concentration in the 50' St. basin sample. The opposite occurred for the samples taken during the second storm event. However, variation on the various forms of nitrogen in the stormwater runoff is not as drastic as that for baseflow samples.

Another nutrient of interest was phosphorus. Although this is not considered the limiting nutrient in the McKay watershed, total phosphorus concentrations at all stations also varied significantly, although not as dramatically as total nitrogen. Phosphorus concentrations seem to show similar pattern in both stormwater and baseflow samples. Total phosphorus concentration ranged between 0.15 and 0.76 mg/L. As expected, the majority of the phosphorus is in orthophosphate form.

Total nitrogen and total phosphorus were also measured in the sediment samples collected in 1997. Since a large portion of the nutrients in the sediment is associated with the organic matter present, sediment nutrient levels tended to follow the same basic trends exhibited by TOC. The highest levels of both nitrogen and phosphorus were measured in the Palm River with the lowest levels measured in northwest McKay Bay. Sediment nitrogen levels ranged from 122 to 3990 mg/kg and averaged 804 mg/kg while phosphorus concentrations ranging from 170 to 5080 mg/kg with an overall average of 1119 mg/kg.

The ratio of sediment nitrogen to phosphorus can often provide information of the source of the nitrogen and phosphorus found in the sediments as well as information on the amount of nutrient resulting from anthropogenic sources. Sediments at 1997 stations exhibited nitrogen-to-phosphorus (N\P) ratios ranging from 0.1 to 1.7 with an average of 0.8. Generally, these N/P ratios suggest a combination of soil humus and terrestrial plant material as a primary source of nitrogen and phosphorus in the sediments (Meybeck, 1982). Higher N/P ratios were measured for Palm River and upper McKay Bay sediments reflecting increased potential nitrogen inputs from aquatic plants or anthropogenic nitrogen sources, such as fertilizers.

Toxic Organic Chemicals

Several analytes classified as "toxic" pollutants were detected in baseflow and/or stormwater samples including: O&G/TPH, phthalates, foaming agents, bis(2-chloroethyl)ether, malathion, and pentachlorophenol.

The presence of total petroleum hydrocarbons (TPH) in stormwater samples indicates runoff from transportation land uses or industrial areas where fuels are released from vehicles, maintenance areas, leaking distribution pipes, or other spills. Petroleum releases are a primary anthropogenic source of PAHs identified as sediment COPCs in McKay Bay. Petroleum hydrocarbons were detected in stormwater from both the 29th and 50th St. basins. In 29th St. basin stormwater, TPH concentrations were 243 ug/I and 113 ug/l for the 12/97 and 1/98 storm events, respectively. In 50th St. basin stormwater, TPH concentrations were 318 ug/l and <100 ug/l (below detection) for the 12/97 and 1/98 storm events, respectively.

Phthalates (butylbenzyl phthalate, di(2-ethylhexyl)phthalate [DEHP], and di-n-butyl phthalate) were detected in stormwater, but also in the equipment blank suggesting potential contamination of sampling equipment. However, DEEP was detected (30.6 ug/1) at approximately 10-times the WQC (L3 ug/l) in the 1/98 stormwater sample for the 29' Street basin.

Foaming agents, or surfactants, reported as linear alkylbenzenesulfonate (LAS), are widely used synthetic surfactants in domestic detergents. LAS was detected at low concentrations in baseflow for all three basins, with the maximum concentration in the 43rd St. basin (2.25 mg/1) above the Florida water quality criterion (0.5 mg/1). The presence of surfactants in the 43rd St. discharge may be attributable to an industrial release (spill or other illicit discharge).

Bis(2-chloroethyl) ether was not detected in stormwater or baseflow samples from the 29th or 50th St. basins, but was detected at significant concentrations in baseflow from the 43rd St. basin. This chemical is used as an industrial solvent, soil fumigant, or textile scouring agent; its presence in the 43rd St. discharge is likely due to an industrial release (spill or other illicit discharge). While no water quality standard has been promulgated for this chemical, it has been classified by U.S. EPA as a probable human carcinogen. Bis(2-chloroethyl) ether does not appear to be highly toxic to aquatic life) or persistent in the environment, or bioaccumulate significantly.

Malathion was detected in baseflow samples for the 29th and 43rd St. basins at one to two orders of magnitude above the water quality standard. The presence of malathion in baseflow samples is likely due to aerial spraying for med fly control in the Spring of 1997, a few weeks preceding the baseflow sampling event.

Pentachlorophenol (PCP) was detected at low levels in one stormwater sample from the 501 St. basin (0. 13 ug/1). This concentration was well below the Florida freshwater and marine criteria and may result from natural sources. PCP was not detected in baseflow samples.

Metals

Eleven trace metals or metalloids were detected in baseflow and/or stormwater samples including: arsenic, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc. With the exception of cadmium, all of these metals are considered essential nutrients for biological organisms, but are toxic to sensitive organisms at elevated concentrations. Five metals were detected at concentrations significantly above Florida water quality criteria. In addition, the reported dissolved fraction for five of these metals including copper, lead, mercury, nickel, and zinc was 30-50%, or higher. Because potential risks increase with increasing dissolved fraction (increased bioavailability) and appropriate treatment methods differ for dissolved versus particulate associated metals, consideration of pollutant form is an important consideration for reduction of risks associated with stormwater discharges. Sediment data collected for this study were used to identify pollutants depositing in particulate form. Because ' of the large differences in the sediment types found in the McKay Bay system, metal to aluminum ratios were also utilized to evaluate potential differences between background and site conditions (FDEP 1988).

Copper. Possible sources of copper include stormwater runoff containing copper-based algaecides, pesticides, and fertilizers, domestic wastes, and industrial discharge. For baseflow samples, average total copper concentrations ranged from 1.4 to 11.6 ug/l, with concentrations in the 431 and 50' St. basins exceeding Florida water quality criteria. For stormwater samples, average total copper concentrations for the 431 and 501 St. basins (32.7 and 28.8 ug/l, respectively) were well above Florida water quality criteria. Sediment copper concentrations ranged from 1.8 to 425 mg/kg, with the highest copper concentration observed in upper McKay Bay. Copper to aluminum ratios for stations in upper McKay Bay were above the expected range; ratios for remaining stations were within or at the upper limit of the expected range. These results indicate that copper associated with suspended particulates is depositing near stormwater outfalls. The dissolved fractions for baseflow (46-5 7%) and stormwater (29-48%), however, suggest that appropriate treatment methods must also address copper in dissolved form in addition to particulate removal.

Lead. Possible sources of lead in the environment include runoff from transportation land uses (roadside runoff, automobile emissions, battery disposal) and discharges from industrial areas. For baseflow samples, average total lead concentrations ranged from 2 to 3 ug/l, with concentrations in all basins sampled exceeding Florida freshwater criteria. For stormwater samples, average total lead concentrations for the 43' and 50' St. basins (6.0 and 8.5 ug/l, respectively) exceeded Florida freshwater and marine criteria. Lead in sediments averaged 47.5 mg/kg and ranged from 7.3 to 156 mg/kg, with the highest lead concentrations observed in upper McKay Bay and East Bay. For seven of the eight sampling sites, lead to aluminum ratios exceeded the expected range. These results indicate that lead associated with suspended particulates is depositing near stormwater outfalls. The dissolved fractions for baseflow (29-41%) and stormwater (51-75%), however, suggest that appropriate treatment methods must also address lead in dissolved form in addition to particulate removal.

Mercury. Possible anthropogenic sources of mercury in the environment include industrial discharges, stormwater runoff containing pesticides, and atmospheric deposition. For baseflow samples, average total mercury concentrations were below detection limits (0. 1 jig/1) for all stations. For stormwater samples, average total mercury concentrations for the 431 and 501 St. basins exceeded Florida freshwater and marine criteria (0.2 and 0.3 ug/l, respectively). Mercury concentrations at six of the eight sediment stations were near or below the analytical detection limits. Two stations in upper McKay Bay and the Palm River exhibited sediment concentrations of 0.21 and 0.27 mg/kg, respectively, and were above Florida sediment screening criteria. Due to the poor relationship of sediment mercury concentrations with aluminum levels, no analysis of the mercury to aluminum ratios was conducted (FDEP 1988). The dissolved fractions for samples at both stormwater stations were approximately 47%, suggesting that removal of mercury not associated with (large) particulates is an important consideration for treatment options.

Nickel. For baseflow samples, average total nickel concentrations ranged from less than 2.9 ug/l to 56.2 ug/l, with concentrations in the 431 St. basin exceeding freshwater and marine water quality criteria. For stormwater samples, average total nickel concentrations for the 43' and 50' St. basins (7.5 and 4.9 ug/l, respectively) were below freshwater and marine water quality criteria. Nickel in sediments ranged from 1.82 to 14.7 mg/kg with maximum concentrations in upper McKay Bay and the Palm River. Because all sediment nickel concentration were below screening criteria, nickel to aluminum ratios were not evaluated. The average dissolved fractions for baseflow (41-48%) and stormwater (33-44%), however, suggests that removal of nickel not associated with (large) particulates is an important consideration for treatment options.

Zinc. Possible anthropogenic sources of zinc include runoff from transportation land uses (roadside runoff, automobile emissions), stormwater containing fertilizers and pesticides, and industrial discharge. For baseflow samples, average total zinc concentrations were below 30 ug/l, with concentrations in all basins sampled below freshwater and marine criteria. For stormwater samples, average total zinc concentrations for the 431 and 50' St basins (113.7 and 121.5 ug/l, respectively) were well above freshwater and marine criteria. Zinc in sediments averaged 124 mg/kg and ranged from 14 to 361 mg/kg with a maximum concentrations in upper McKay Bay and the Palm River. For most stations, zinc to aluminum ratios fell within or on the upper border of the expected range. For several stations in upper McKay Bay, zinc to aluminum ratios were well above the expected range. These results indicate that zinc associated with suspended particulates is depositing near stormwater outfalls. The dissolved fractions for baseflow samples (40-99%) and stormwater (50-52%), however, suggest that appropriate treatment methods for zinc must address dissolved forms in addition to particulate removal.

DISCUSSION

Due to the variable and intermittent nature of stormwater discharges, pollutant characterization and estimation of loads to receiving waterbodies are often based on simple models or limited sampling efforts. Traditionally, stormwater management actions including selection of BMPs and treatment methods are based on the assumption that a large portion of the pollutant load is in particulate form. As shown by the results of this study, however, pollutants typically associated with solids loading may also be present at significant levels in dissolved form.

The results of this analysis have implications for the type of treatment that would be effective for pollution control. For example, it was determined during this study that the simple retrofit of existing flood control facilities as detention ponds for water quality would be probably effective for removal of the TKN associated with the particulate material. The TKN concentration represents, on the average, approximately 50 % of the total nitrogen. However, the removal of the additional 50% of the total nitrogen is in NOx form. which is generally in dissolved form. Detention would not be effective as a treatment method. It was decided that a combination detention/created wetland would be more appropriate.

The results of this study- also indicated that several toxic chemicals such as petroleum hydrocarbons and heavy metals were present above water quality criteria in both baseflow and stormwater discharges. For permitted wastewater discharges, metals and organic chemicals must be removed prior to discharge to minimize potential adverse (toxic) effects on biota in the receiving waterbody. For stormwater discharges, consideration oft otal and dissolved forms of toxic pollutants is also important to reduce impacts to receiving waterbodies; as well as minimize potential exposures in treatment systems, particularly where constructed wetlands may be utilized as habitat.

For the organic chemicals and metals identified as pollutants of concern in stormwater discharges to the McKay Bay system, several BMPs were selected as recommended treatment options to reduce pollutants in both particulate and/or dissolved forms. These included projects incorporating both detention and wetland treatment. These BMPs will serve to reduce solids and particulate nutrient loadings as well as removal of toxic pollutants associated with particulates. They will also be effective for removing toxic pollutants identified as COPCs in baseflow and stormwater (PAHs, phthalates, LAS, copper, lead, mercury, nickel, and zinc).

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