University of the Virgin Islands Conceptual Stormwater Management Plan Coral Bay Watershed Final Letter Report (May 2005)

Background

The Coral Bay watershed, shown in **Figure 1**, is located in the southeastern portion of the island of St. John, U.S. Virgin Islands (USVI) and consists of approximately 3,000 acres or 4.7 square miles. This watershed has the highest population growth rate in the USVI. The watershed, which is typical of those throughout the Virgin Islands has severe topographic relief, highly erodible soils, many miles of unpaved roads, and significant new construction. These factors have all contributed to increased stormwater runoff and associated sedimentation in Coral Bay, the watershed's receiving water body. In fact, sediment accumulation rates have increased by approximately one order of magnitude in Coral Bay over the past 100 years, likely in response to an increase in antropogenic activities (University of the Virgin Islands [UVI], 2003). This has resulted in the bay's poor water quality and deterioration of marine resources in waters extending offshore. Coastal water quality has been stedily deteriorating due to the influx of sediment, sewage, and other pollutants (UVI-Cooperative Extension Service [CES], 2002).

Figure 1 – Coral Bay Watershed, St. John, USVI

To date, stormwater best management practices (BMPs) have not been implemented to address this growing problem. The University of the Virgin Islands (UVI) through its Eastern Caribbean Center (ECC) has retained CDM to provide consulting engineering services to develop a conceptual stormwater management plan (SWMP) for a pilot subbasin in the Coral Bay watershed. This letter report will summarize the results of the data collection effort, a preliminary engineering analysis, and conceptual design alternatives.

Data Collection

This section summarizes the data collection effort. The data collected in this effort will be used to perform the preliminary engineering analysis and evaluate conceptual alternatives. Data collected from the UVI as well as governmental agencies include reports and studies, Geographic Information System (GIS) coverages, topographic data, soils and land use data. The following narrative describes the process involved in obtaining these data and provides a summary of the data collected.

Existing Studies and Reports

CDM identified a number of reports either through the ECC or through other research. The existing studies and reports that were collected and reviewed as part of this effort include:

- Puerto Rico and Virgin Islands Precipitation Frequency Project, Update of Technical Paper No. 42 and Technical Paper No. 53,Twelfth Progress Report (U.S. National Weather Service, 2003)
- Sedimentary Framework of Coral Bay, St. John, USVI: Anthropogenic Implications Final Report (UVI, 2003)
- Virgin Islands Environmental Protection Handbook (University of the Virgin Islands Cooperative Extension Service, 2002)
- Soils Survey of the United States Virgin Islands (U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), 1998)
- Technical Release No. 55 (TR-55): Urban Hydrology for Small Watersheds (NRCS, 1986)
- Technical Paper No. 42: Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands (U.S. Weather Bureau, 1961)

GIS Data

CDM obtained GIS data for the study area from ECC in order to provide visual representation of the watershed as well as to develop the hydrologic parameters described under *Preliminary Engineering Analysis*. The GIS data obtained include:

- Digital 2-foot topographic contour GIS coverage obtained from the ECC. This data set was developed by the U.S. Army Corps of Engineers using aerial photography taken in 1994;
- 2000 digital ortho-photo quadrangles (DOQs) developed for the National Oceanic and Atmospheric Association (NOAA);
- Existing land use (1999);
- Coral Bay watershed boundary;
- Parcels;
- Buildings;
- Soils; and
- Roads.

Problem Areas

Figure 2 – Unpaved Road in Coral Bay Watershed

Problems reported in the watershed are primarily related to untreated and unmanaged stormwater runoff that is conveyed through valleys in the hillside commonly referred to as "guts". This runoff in many cases is conveyed over unpaved roads, an example of which is shown in **Figure 2,** where it can pick up sediment and smaller debris. As the runoff accumulates further down in the guts, larger rocks and small boulders may also be carried by the stream. Examples of well defined guts are shown in **Figures 3** and **4**.

Figure 3 – Well-Defined Gut

Figure 4 – Well-Defined Gut Upstream of its Outfall to Coral Harbor

The end result is large amounts of material being eroded from unpaved roads, guts, and other unstabilized areas and deposited at the shoreline in the mangroves or in the case of sediment and smaller particles, being carried into Coral Bay itself where it eventually settles. CDM performed a preliminary field reconnaissance of the Coral Bay Watershed in August 2004 to assess the extent of the problem areas. As mentioned previously, stormwater runoff is largely untreated before it discharges to Coral Bay. The stormwater facilities that do exist in the watershed are predominantly to provide conveyance. They are typically located at the end of the gut system where stormwater is conveyed under road crossings.

During the site visit, CDM field surveyed several of the guts as well as the outfall points of discharge. At one location in the northwest corner of Coral Harbor, an energy dissipater at one of the outfalls has been installed to reduce runoff velocity as well as to let materials settle out. The structure appears to be effective in reducing velocity and trapping sediment and smaller materials (see **Figure 5**). The effectiveness of this structure, however, largely depends on maintenance as materials will accumulate with each storm event. Once the structure is filled with material, energy dissipation is reduced and additional sediment can no longer be trapped and instead is flushed into the Bay. The deposition of materials was also apparent just upstream of this road crossing, as shown in **Figure 6**.

Figure 5 – Energy Dissipation Structure

Figure 6 – Accumulated Debris Upstream of Outfall to Coral Harbor

Preliminary Engineering Analysis

CDM used the data collected to estimate the volumes and rates of stormwater runoff from the Coral Bay Watershed. CDM estimated these volumes and rates using the hydrologic component of the Interconnected Channel and Pond Routing (ICPR) Windows Version 3.02 stormwater model developed by Streamline Technologies®. The model was used to simulate two single event design storms appropriate for the study area. Due to the size of the Coral Bay Watershed, its generally steep slopes, and the relatively limited areas available for BMPs, the engineering analysis and conceptual design considered more typical storm events (i.e., 1- and 2-year/24-hour design storm events) rather than more extreme events (e.g., 10-year/24-hour event). A more detailed description of the development of the hydrologic model is provided below.

Hydrologic Model

The hydrologic component of the ICPR model is used to evaluate rainfall, runoff, and infiltration characteristics of an area. ICPR has three methods for generating stormwater runoff: the Soil Conservation Service (SCS) unit hydrograph method, the Santa Barbara method, and the Overland Flow method. For this effort, the SCS unit hydrograph method was used. The ICPR model has two components for the determination of the volume and rate of stormwater runoff. The first component is based upon the amount of directly connected impervious area (DCIA) represented by a percentage of the contributing area. The resulting runoff from rainfall over the DCIA does not pass over any pervious area and thus does not infiltrate into the soil. The second component consists of the pervious and impervious areas that are not directly connected to the PSMS and thus are subject to infiltration. The SCS unit hydrograph method uses a curve number (CN) to determine the runoff volume from this second component. The CN method relates rainfall to direct runoff as a function of soil storage (estimated using soil type and land use cover). A more complete documentation of the model's background and theory can be found in the ICPR Version 2.20 User's Manual (September 1995) or in the ICPR Version 3.0 online help system.

Hydrologic Parameters

Hydrologic model parameters used for the model simulations are described below. The hydrologic parameters compiled for each subbasin include the contributing area, DCIA, time of concentration, and CN.

Subbasin Delineation

Subbasins in the watershed were delineated using the available digital 2-foot topographic contours as well as the 2000 DOQs. The watershed was divided into eight (8) major subbasins which are shown in **Figure 7**. Hydrologic units are generally defined by natural physical features or constructed stormwater conveyance systems, which control and direct stormwater runoff to a common outfall.

For the purposes of this report, the major subbasins were assigned an identifier based on the water body serving the area. The tributary area of each subbasin unit was determined using the computational capabilities of the GIS software package ArcView® Version 9.0. The eight hydrologic units averaged approximately 370 acres in size with a minimum of 60 acres and a maximum of 1,603 acres. The subbasins along with their respective tributary areas are listed in **Table 1**.

Table 1
Coral Bay Watershed
Conceptual Stormwater Management Plan
Subbasins

Subbasin	Tributary Area (acres)	Time of Concentration (min)
CH – Coral Harbor	1,603	121.6
DB – Drunk Bay	60	24.1
FB – Friis Bay	78	32.7
HH – Hurricane Hole	451	29.0
JFB – Johns Folly Bay	124	36.5
JB – Johnson Bay	184	49.5
PB – Privateer Bay	122	26.2
RB – Round Bay	337	27.9

Time of Concentration

The time of concentration (T_c) is the time for stormwater runoff to travel from the hydraulically most distant point of the watershed to the point of interest (outflow from the area). For ponded areas, the point of interest chosen was the centroid of ponding. The T_c for each subbasin was determined by identifying the longest flow path using the 1994 2-foot digital contour GIS coverage and the 2000 DOQs provided by the ECC. The methodology used for calculation of T_c is consistent with the procedures described in TR-55 (NRCS, 1986). Each flow path was then subdivided into three types of flow (sheet flow, shallow concentrated flow, and open channel/pipe flow). The total T_c is the sum of the travel times for each of the three types of flow. In most cases, the sheet flow component accounts for over 20 percent of the total time of concentration for the hydrologic unit, even though it makes up a small percentage of the total flow length. Analysis of the T_c values for the Coral Bay subbasins range between 24.1 minutes and 121.6 minutes for present conditions and are shown in Table 1.

Rainfall Intensities and Quantities

Rainfall data were used to generate the flows for stormwater evaluations. Data are generally characterized by depth (inches), intensity (inches per hour), frequency, return period (years), duration (hours), spatial distribution (locational variance), and temporal distribution (time variance). According to TR-55 (NRCS, 1986), the highest peak discharges from small watersheds are usually caused by intense, brief rainfalls that may occur as distinct events or as part of a longer storm. These intense rainstorms do not usually extend over a large area and intensities vary greatly. The analyses of some systems (e.g., a large stormwater treatment facility) consider a major design storm such as a 25-year event. However, for the purposes of this SWMP, the 1- and 2-year/24-hour design storm events were simulated due to the nature of the watershed and its vulnerability to erosion and sedimentation during the smaller and more frequent events. A common practice in a hydrologic runoff analysis is to develop a synthetic rainfall distribution to use in lieu of actual storm events. The distribution includes maximum rainfall intensities for the selected design frequency arranged in a sequence that is critical for producing peak runoff. The length of the most intense rainfall period contributing to the peak runoff rate is related to the T_c for the watershed.

For the size of the watersheds for which NRCS usually provides assistance, a storm period of 24 hours was chosen for the synthetic rainfall distributions. The 24-hour storm, while longer than that needed to determine peaks for these drainage areas, is appropriate for determining runoff volumes. Therefore, a single storm duration and associated synthetic rainfall distribution can be used to represent not only the peak discharges but also the runoff volumes for a range of drainage area sizes.

The intensity of rainfall varies considerably during a storm as well as geographic regions. To represent various regions of the United States and its territories, NRCS developed four synthetic 24-hour rainfall distributions (I, IA, II, and III) from available National Weather Service (NWS) duration-frequency data or local storm data. For the Virgin Islands, NRCS recommends the use of type II, which represents the most intense short duration rainfall.

According to the Virgin Islands Environmental Protection Handbook (2002), the 24-hour rainfall volumes for the island of St. John (Cruz Bay) for the various design storm events include:

- 1-year – 2.8 inches of rainfall
- 2-Year – 3.9 inches of rainfall
- 5-Year – 5.5 inches of rainfall
- 10-Year – 6.6 inches of rainfall
- 25 -Year – 8.0 inches of rainfall
- 50 -Year – 9.2 inches of rainfall
- 100 -Year – 10.5 inches of rainfall

The volumes for the 1- and 2-year/24-hour storm events were applied to the NRCS type II rainfall distribution of a 24-hour duration. The peak rate factor (K′) accounts for the effect of watershed storage and is a parameter used to reflect the shape of the runoff hydrograph. A peak rate factor (K') of 575 was used for application of the NRCS unit hydrograph method due to the steep slopes throughout the watershed.

Land Use Data
The volume and the peak rate of runoff is a function of the type of land use that is present. An accurate representation of the existing land use is needed to determine a reasonable estimate of stormwater runoff in a watershed. Existing land uses (1999) for the Coral Bay Watershed were obtained from the ECC as shown in **Figure 8**. CDM reviewed these land use data and compared them to the 2000 DOQs. Based on review of the aerials, some of the land use categories were reassigned to more accurately represent the actual land cover. Land use determination is needed for the purpose of developing the curve numbers. As an example, a large portion of the watershed is assigned "undeveloped" as a land use category. When reviewing the aerials, the majority of this "undeveloped" land is actually forested. Therefore a "forest" land use was assigned to these areas for the purposes of developing more accurate curve numbers. A breakdown of the land use by category and acreage for each of the subbasins as well as its reassigned land use is provided in **Table 2**. As indicated in Figure 8, the land uses within the watershed are predominantly designated as parks/recreation/open Space (48%) and undeveloped (42%).

Soils Data
Soils data are used to evaluate stormwater runoff, infiltration, and recharge potential for pervious areas. Information on soil types was obtained from the U.S. Department of Agriculture (USDA) NRCS (formerly SCS) Soils Survey of the United States Virgin Islands (NRCS, 1998) as well as in digital format from the ECC. Each soil type has been assigned to a soil association, a soils series, and to one of the four Hydrologic Soil Groups (A, B, C, or D) established by the NRCS. Hydrologic Soil Group A is comprised of soils having very high infiltration potential and low runoff potential. Those soils with moderate infiltration rates when thoroughly wetted are classified as Hydrologic Soil Group B. Group C soils are those soils with low infiltration rates while Hydrologic Soil Group D is characterized by soils with a very low infiltration potential and a high runoff potential. Dual hydrologic groups, A/D, B/D, and C/D, are given for certain wet soils that can be adequately drained. The first letter applies to the drained condition, while the second applies to the undrained condition. For the purposes of developing curve numbers, a dual hydrologic group is assigned the characteristics of a "D" soil as a more conservative approach. **Table 3** lists the acreages of soil series identified in the Coral Bay watershed by subbasin and their corresponding NRCS hydrologic soils group classification. The digital soils coverage was available from the ECC and imported into ArcView® Version 9.0. **Figure 9** shows a map of the NRCS hydrologic soils groups for the Coral Bay Watershed. As indicated in Figure 9, the soils within the watershed fall predominantly within the "D" soils group (approximately 93%) and have high runoff potential.

Table 2
Coral Bay Watershed
Conceptual Stormwater Management Plan
Land Use

Subbasin	Land Use	Reassigned Land Use	Area (acres)	% of Total Land Use
CH – Coral Harbor	Agriculture	Agriculture	13.4	0.45%
	Commercial	Commercial	0.9	0.03%
	Low Density Residential	Low Density Residential	160.0	5.44%
	Parks/Recreation/Open Space	Forest	801.0	27.21%
	Public Facilities	Institutional	6.5	0.22%
	Undeveloped	Forest	617.25	20.97%
	Waterfront/Marine	Industrial	3.0	0.10%
DB – Drunk Bay	Hotel/Resort	Commercial	1.4	0.05%
	Low Density Residential	Low Density Residential	0.2	0.01%
	Parks/Recreation/Open Space	Forest	38.9	1.32%
	Undeveloped	Forest	18.9	0.64%
FB – Friis Bay	Low Density Residential	Low Density Residential	17.8	0.60%
	Parks/Recreation/Open Space	Forest	0.2	0.01%
	Undeveloped	Forest	58.9	2.00%
HH – Hurricane Hole	Low Density Residential	Low Density Residential	5.4	0.18%
	Parks/Recreation/Open Space	Forest	439.4	14.93%
	Undeveloped	Forest	0.1	0.00%
JFB – Johns Folly Bay	Low Density Residential	Low Density Residential	20.7	0.71%
	Parks/Recreation/Open Space	Forest	7.8	0.75%
	Undeveloped	Forest	95.2	4.77%
JB – Johnson Bay	Low Density Residential	Low Density Residential	20.9	0.70%
	Parks/Recreation/Open Space	Forest	22.0	0.27%
	Undeveloped	Forest	140.5	3.23%
PB – Privateer Bay	Low Density Residential	Low Density Residential	1.4	0.05%
	Undeveloped	Forest	116.6	3.96%
RB – Round Bay	Low Density Residential	Low Density Residential	42.8	1.45%
	Parks/Recreation/Open Space	Forest	108.2	3.68%
	Undeveloped	Forest	184.0	6.25%
		Totals:	2943.4	100%

Table 3
Coral Bay Watershed
Conceptual Stormwater Management Plan
Hydrologic Soil Groups

Subbasin	Hydrologic Soils Group	Acres
CH – Coral Harbor	A	60.1
	B	86.1
	B/C	5.3
	B/D	933.7
	D	516.7
	WATER	0.3
DB – Drunk Bay	B	4.0
	B/D	3.4
	D	52.0
FB – Friis Bay	B	5.1
	B/D	25.3
	D	46.5
HH – Hurricane Hole	B	4.2
	B/D	22.1
	D	418.4
	WATER	0.2
JB – Johnson Bay	B	17.0
	B/D	130.1
	D	36.3
JFB – Johns Folly Bay	A	1.3
	B	3.5
	B/D	70.1
	D	48.8
PB – Privateer Bay	D	118
RB – Round Bay	A	0.7
	B/D	8.8
	D	325.6

Curve Numbers

The curve numbers, which are used to determine how much of the rainfall will be converted to runoff, were calculated based on the land use distribution and hydrologic soil group distribution in each subbasin. The SCS provides information on relating soil group types to the curve numbers as a function of soil cover, land use type, and antecedent moisture condition. **Table 4** shows the relationship between CN values, hydrologic soils group, and land use type based upon the SCS methodology. The assumed percent imperviousness (based on land use) is also indicated in Table 4. This relationship was then used to compute a composite CN value for each subbasin. A summary of the CN values under existing use conditions by hydrologic unit is presented in **Table 5**.

Table 4
Coral Bay Watershed
Conceptual Stormwater Management Plan
SCS Hydrologic Soils Group Curve Numbers

St. John Land Use Inventory	Reassigned Land Use	Percent Impervious	Curve Number for Each SCS Hydrologic Group			
			A	B	C	D
Low Density Residential	Low Density Residential	30	57	72	81	86
Commercial	Commercial	85	89	92	94	95
Hotel/Resort	Commercial	85	89	92	94	95
Waterfront/Marine	Industrial	72	81	88	91	93
Public Facilities	Institutional	85	89	92	94	95
Parks/Recreation/ Open Space	Forest	0	36	60	73	79
Undeveloped	Forest	0	36	60	73	79
Agriculture	Uncultivated Agricultural Land (UVICES 2002)	0	74	83	88	90

Table 5
Coral Bay Watershed
Conceptual Stormwater Management Plan
Curve Numbers

Subbasin	Curve Number
CH – Coral Harbor	78
DB – Drunk Bay	78
FB – Friis Bay	80
HH – Hurricane Hole	79
JFB – Johns Folly Bay	79
JB – Johnson Bay	78
PB – Privateer Bay	79
RB – Round Bay	80

CDM intersected the land use and SCS Hydrologic Soils Group with the subbasin delineation coverage using Arcview® Version 9.0. CDM then exported the resulting dbf file to a Microsoft® Access database and used a series of queries to calculate the composite CN value using predefined look-up tables and the percentages (by area) of the hydrologic coverages for each subbasin. It should be noted that the percent of water body was not included in the calculation of the CN but was input to the model as DCIA.

Hydrologic Modeling Results

Once the hydrologic component of the ICPR stormwater model was developed, CDM performed simulations of the 1- and 2-year/24-hour design storm events for existing land use conditions for the Coral Bay Watershed. The predicted peak volumes and flows for each of the subbasins during the simulated storm events are shown in **Table 6**.

Table 6
Coral Bay Watershed
Conceptual Stormwater Management Plan
Simulated Peak Flows

Subbasin	1-year/24-hour Storm Event Volume (ac-ft)	1-year/24-hour Storm Event Peak Flow (cfs)	2-year/24-hour Storm Event Volume (ac-ft)	2-year/24-hour Storm Event Peak Flow (cfs)
CH – Coral Harbor	132.0	533.6	241.6	1021.1
DB – Drunk Bay	4.9	61.2	9.0	114.4
FB – Friis Bay	7.2	74.1	12.7	135.3
HH – Hurricane Hole	39.2	436.5	70.8	809.5
JFB – Johns Folly Bay	10.8	104.8	19.5	195.3
JB – Johnson Bay	15.1	118.6	27.7	224.8
PB – Privateer Bay	10.6	127.2	19.2	234.4
RB – Round Bay	30.9	353.2	55.1	636.0

Conceptual Design Alternatives Analysis

Based on field reconnaissance as well as the results of the preliminary engineering analysis, CDM identified conceptual alternatives to address the untreated and unmanaged runoff and sediment deposition into Coral Bay. Various stormwater BMPs considered are discussed further below. In general, stormwater BMPs are typically more easily implemented in new projects where their design can be incorporated into the overall development plan. After development has occurred, the lack of available land severely limits the implementation of cost-effective management options (UVI-CES, 2002).

Stormwater BMPs

As indicated in **Table 7**, various stormwater BMPs were considered for the Coral Bay watershed. These BMPs fall into three primary categories: source controls, end of pipe treatment, and detention basins. Since the Coral Bay sediment source is largely generated from natural areas (nonpoint), sediment management through source controls alone would be wide-spread and likely prohibitively expensive. However, natural vegetative filter strips and check dams are examples of source controls that should be incorporated into the existing landscape where possible. Also, future development should be required to incorporate appropriate source controls into the site design of new development projects. The use of construction BMPs, such as silt fencing and sediment traps, should also be required and enforced during construction of roadway and new development projects.

Table 7
Coral Bay Watershed
Conceptual Stormwater Management Plan
Stormwater BMPs Considered

BMP Type	Primary Use	Advantages	Disadvantages
Source Controls			
Regrading and Stabilization Practices	Stabilize soils and reduce erosion	Most direct method to reduce erosion and sedimentation Preserves natural vegetation	Wide-spread implementation needed. Very expensive
End of Pipe Treatment			
Energy Dissipater	Reduce velocity of watercourse	Small footprint Relatively inexpensive	Not ideal for settling Limited sediment storage
Vortex Unit	Sediment and debris removal	Small footprint Relatively inexpensive	Limited sediment storage
Baffle Box	Sediment and debris removal	Small footprint Easy to maintain	Requires more frequent maintenance than ponds
Detention			
Pond	Sediment removal and uptake of other pollutants	More effective BMP Less frequent maintenance	Requires more space and flatter topography
Wetland	Detention and vegetative uptake of pollutants	More effective treatment through vegetative uptake	Must maintain hydrology Not ideal for primary settling

End-of-pipe devices such as energy dissipaters and flow-through separators (baffle boxes and vortex units) are designed to slow or detain a water course (or a portion thereof) with a device at the end of pipe or stream. These devices are designed to allow settling of sediment and/or to reduce downstream velocities and subsequent erosion. Benefits of end-of-pipe devices are that they are typically less expensive, can be implemented within smaller and steeper areas, and are more easily maintained. Disadvantages are that they have limited capacities, are designed for smaller flows, and require more regular maintenance.

Detention basins, such as ponds and constructed and natural wetlands, are designed to temporarily hold stormwater allowing for sediments and other pollutants to settle out before being discharged at a controlled rate. These basins should be sized to provide a minimum detention time for the target storm capture volume. This minimum detention (or residence time) represents the time required for sediments to settle out of the water column within the detention basin and be removed from the runoff stream. Advantages of detention BMPs include the ability to treat larger flows and less frequent maintenance. Disadvantages include the need for larger available areas and relatively flat topography for implementation.

BMP Conceptual Design Recommendations

Conceptual design BMPs recommended for Coral Bay include baffle boxes and detention ponds. Baffle boxes are recommended over vortex units based on a longer detention time and greater sediment storage capacity. Use of energy dissipaters is recommended as needed to slow a water course or in conjunction with a baffle box, but not instead of a baffle box. Use of ponds over wetland to provide detention is recommended based on the need for primary settling and sediment storage. Where possible in conjunction with a detention pond, additional detention treatment is recommended using extended detention and/or wetland treatment. While the design of source controls is not specifically addressed, they should also be retrofit where practical and be required in the design of new development.

Implementation of the recommended BMPs should be based on subbasin size, available land, and the degree of topographic relief characteristic of the watershed. Design considerations of end of pipe treatment and detention BMPs are discussed further below.

BMP Design Considerations

Several of the subbasins have extremely steep slopes (average slope of approximately 25 percent) that are continuous almost to the edge of the shoreline. Examples include the Drunk Bay, Friis Bay, Johnson Bay, portions of Coral Harbor, Hurricane Hole, and Privateer Bay subbasins. The steep nature of these subbasins do not allow for BMPs that are land intensive such as detention ponds. Therefore, end-of-pipe treatments should be considered to retrofit areas with steep slopes and/or where there is little space available. However, these units are typically designed to accommodate smaller flows. To address the smaller subbasins (i.e., Drunk Bay and Friis Bay), typical baffle boxes could be used to capture sediment from portions of the discharge during smaller storm events. To address the medium subbasins (i.e., Johnson and Privateer Bay), extended baffle boxes would be needed to treat portions of the discharge during typical storm events. Baffle boxes may not be appropriate in the larger subbasins (i.e., Coral Harbor and Hurricane Hole) due to the excessive flow and sedimentation loads. Instead detention ponds, if possible, are recommended for the larger basins.

Detention BMPs are more suitable for larger subbasins with available land areas and milder topographic relief. Where feasible, larger stormwater facilities should be considered within subbasins that generate larger flows. Subbasins that appear to have areas with milder topographic relief include portions of Coral Harbor, Johns

Folly Bay, portions of Johnson Bay, and portions of Round Bay. The advantages of detention ponds are that they have greater capacities, require less frequent maintenance, and can be used to treat greater flows. The disadvantages are that they require more land area, which in turn drive up costs, and can be more difficult to maintain.

Regardless of the BMP method selected (detention or end-of-pipe), design considerations are similar. The BMP should be sized according the established capture objective (e.g., the first inch of runoff). The detention (or residence) time within the BMP must also be determined to capture the target sediment (e.g., fine sand) and to meet target removal rate (e.g., 80%) from the treated runoff. The required detention time is based on the runoff sediment characteristics and the target removal rate. Annual maintenance requirements (volumes and frequencies) can be estimated based on the capture and removal objectives and the sediment storage capacity of the BMP.

Depending on the size of the subbasin and the sediment load carried by the runoff, it may be necessary to implement more than one BMP device in series or within different areas of the subbasin to meet the target capture and removal objectives. Also, additional data collection (e.g., topographic survey, geotechnical investigation, stormwater runoff quality, and settleability tests) specific to the subbasins to be treated is needed to confirm BMP performance and to support more refined designs of proposed BMP devices.

To clarify the conceptual design process, pilot areas within the Coral Harbor subbasin are identified for conceptual design.

BMP Conceptual Pilot Design Parameters

Based on discussions and feedback from the ECC, CDM identified pilot areas within the Coral Harbor subbasin to be used for developing conceptual designs. The pilot areas were delineated by dividing a portion of the subbasin into smaller hydrologic units that are tributary to the individual guts, as shown in **Figure 10.** These portions of the Coral Harbor subbasin were selected to pilot the conceptual design for various reasons including: 1) chronic sedimentation problems occur here due to the number of guts as well as the large flows conveyed during storm events; 2) new development is more concentrated in these areas; and 3) these are areas that have milder topographic relief thus allowing more options for BMP design.

In order to develop conceptual designs for the pilot areas, it was necessary to estimate the flows from the individual hydrologic units to determine the sizes of facilities needed to provide sufficient stormwater treatment. The hydrologic units, their areas and estimated peak flows and volumes for the 1-year/24-hour storm event are included in **Table 8**. Flows and volumes for each of the hydrologic units were estimated by multiplying the percent land area of the subbasin by the total amount of peak flow predicted by the ICPR stormwater model for the Coral Harbor subbasin (Table 6). The hydrologic properties of each unit were assumed to be homogeneous throughout the subbasin. The runoff volume generated by the 1-year/24-hour storm event in the Coral Harbor subbasin is approximately 1 inch over the subbasin area.

Table 8
Coral Bay Watershed
Conceptual Stormwater Management Plan
Estimated Pilot Area Peak Flows

Hydrologic Unit	Area (acres)	% Land area of Coral Harbor Subbasin*	Estimated Flow (cfs) 1-year/24-hour event**	Estimated Volume (ac-ft) 1-year/24-hour event**
CH-1	52.6	3.30%	17.5	4.4
CH-2	28.2	1.80%	9.4	2.4
CH-3	132.5	8.30%	44.1	11.0
CH-4	73.8	4.60%	24.6	6.1
CH-5	372	23.20%	123.8	30.6
CH-6	369.7	23.10%	123.1	30.5
CH-7	67.8	4.20%	22.6	5.5
CH-8	97.5	6.10%	32.5	8.1

* Coral Harbor Subbasin Area = 1603 acres
**Predicted ICPR Coral Harbor Subbasin Flow for the 1-year/24-hour event = 533.6 cfs

Conceptual Design Assumptions

To support the conceptual design of the pilot BMPs, the following assumptions were made:

1) BMP design parameters are based on the runoff flow rates and volumes from the 1year/24 hour storm event;

2) Target runoff capture volume is the first inch of runoff over the subbasin;

3) Target sediment is fine sand (0.1 millimeter);

4) Settling velocity of fine sand is approximately 1 foot in 38 seconds (Urquhart, 1959);

5) Sediment must settle a minimum depth of 3 feet to be removed by the BMP;

6) Minimum effective flow depth of the BMP is 3 feet and minimum sediment storage depth is 3 feet;

7) Based on the assumed settling velocity for fine sand and depth (3 feet), the required minimum detention time is approximately 1.9 minutes;

8) A maximum velocity of 0.5 feet per second within the BMP is allowed to minimize re-suspension of settled sediment; and

9) A minimum length to width ratio of 3:1 is desired (especially for baffle boxes) to reduce short circuiting.

Conceptual Management Plan and Pilot Designs

A conceptual management plan was developed for the eight pilot areas as shown on **Figure 11**. The pilot design parameters presented in **Table 9**, include four baffle boxes, two extended baffle boxes, and two detention ponds. For the detention ponds suitable land with relatively flat topography is needed. Therefore, an alternative to the detention ponds located in hydrologic units CH-5 and CH-6 is a detention pond located in hydrologic unit CH-1, as indicated on Figure 11.

For the purposes of this study, extended baffle boxes are defined to be baffle boxes more than 60 feet in length. Vortex units, though effective BMPs, are not recommended since the sediment storage capacities for these units are typically smaller than those available in baffle boxes. Energy dissipaters are also not recommended herein for sediment removal since their primary purpose is to reduce runoff velocities. Energy dissipaters should however be considered in conjunction with recommended BMPs or in areas with erosive velocities that would otherwise have no BMP.

Table 9
Coral Bay Watershed
Conceptual Stormwater Management Plan
Conceptual Pilot BMP Design Parameters

Hydrologic Unit	Recommended BMP	Inflow Pipe Diameter (inches)	Minimum BMP Area (square feet)	Length (feet)	Width (feet)	Minimum BMP Volume (cubic feet)
CH-1	Baffle Box	30	665	45	15	1,995
CH-2	Baffle Box	24	357	33	11	1,072
CH-3	Extended Baffle Box	42	1,676	72	24	5,105
CH-4	Baffle Box	30	935	53	18	2,804
CH-5	Detention Pond	72	14,161	119	119	42,411
CH-6	Detention Pond	72	13,924	118	118	41,936
CH-7	Baffle Box	30	859	51	17	2,576
CH-8	Extended Baffle Box	36	1,235	61	20	3,705

1. Baffle boxes assume an effective length to width ratio of 3 to 1.
2. Detention ponds assume an effective length to width ratio of 1 to 1.
3. BMPs assumes an effective flow depth of 3 feet.

BMP Design Methodology

The design parameters specified in Table 9 satisfy the design assumptions listed above. To illustrate the design methodology, the following steps are presented for hydrologic units CH-2 and CH-5.

The conceptual BMPs are designed to treat flows and volumes associated with the first inch of runoff from the associated hydrologic units (Table 8). For hydrologic unit

CH-2, the BMP must be able to convey and treat up to 9.4 cubic feet per second (cfs) and 2.4 acre-feet of runoff. At this flow rate a 24-inch diameter pipe is recommended to convey the runoff into a baffle box. In order to provide a minimum detention time of 1.9 minutes, the baffle box must have a minimum volume of approximately 1,072 cubic feet (Table 9). Allowing for a three foot effective flow depth from the normal operating water level to the level of sediment storage, the baffle box therefore needs a plan area (length times width) of approximately 357 square feet. Using a length to width ratio of 3.0, the baffle box has a width of 11 feet and a length of 33 feet. The cross sectional area (width times flow depth) of the baffle box is 33 square feet and can therefore convey the peak flow at a velocity of less than 0.5 feet per second (fps).

For hydrologic unit CH-5, the BMP must be able to convey and treat up to 123.8 cfs and 30.6 acre-feet. This flow rate is too high to recommend a standard or extended baffle box (in fact, using this sizing methodology the baffle box would need to be more than 100 feet long). Therefore, for CH-5 (as well as CH-6), a detention pond is recommended. A 72-inch diameter pipe is recommended to convey the runoff to the pond. In order to provide a minimum detention time of 1.9 minutes, the pond must have a minimum volume of 42,411 cubic feet (Table 9). Allowing a three foot effective flow depth from the normal water level to the level of sediment storage, the pond needs a minimum area of approximately 0.3 acre (14,161 square feet) assuming that a 1 to 1 length to width ratio is provided. If a narrower pond is used, due to site constraints, for example a pond with a 3 to 1 length to width ratio, then the pond could be smaller to provide the same level of treatment. If available area exists, a larger pond would provide a greater level of treatment and/or to treat larger areas (more than one hydrologic unit). The detention pond should also be designed with a deeper forebay and a minimum freeboard (e.g., 1 foot) from peak stage to top of bank. Consideration should also be provided to the design of pond access for future maintenance and sediment removal. Conceptual design sketches for the pilot BMPs (baffle box and detention pond) specified for hydrologic units CH-2 and CH-5 are provided in **Figure 12** and **Figure 13**.

Additional Considerations

While the subject evaluation indicates that it may be feasible to implement BMPs within the Coral Bay subbasins to provide water quality treatment and remove sediment, it is important to keep in mind that additional site-specific data is needed to confirm feasibility and support final BMP design. Also, the BMP design parameters developed herein targeted removal of fine sand (0.1 millimeter) from the first inch of runoff. Removal of smaller particles or capture of greater stormwater runoff rates will require additional and/or larger BMP designs. The next step to implement the BMPs is to identify available parcels that will provide the necessary area for the BMP. This should not be difficult for the baffle boxes but it may be a greater challenge for the detention ponds. As indicated above, a larger pond will provide a greater level of treatment and/or treat larger areas, and these objectives should be maximized in the design to the extent possible.