CHAPTER 4

EXISTING STORMWATER DRAINAGE SYSTEM

4.1 INTRODUCTION

The analysis of related stormwater runoff problems requires knowledge of the components which make up the system. Friday Harbor's storm drainage collection and conveyance system, which ultimately delivers stormwater to Friday Harbor, consists of curb inlets, catch basins, piping and open ditches.

The evaluation of the Town's drainage facilities begins with the establishment of an inventory of the existing system's components. Information included in the inventory are pipe size and length, invert elevations at catch basins and inlets, pipe slope and ditch length, slope and configuration. Figure 4-1 is a reduced copy of the base map showing the drainage facilities cataloged in the inventory. The full size base map is included in the sleeve at the back of this document. Base maps provide a tool for Town staff to use in planning for future extensions and for facilities maintenance. The compilation of the total system elements in the Town of Friday Harbor stormwater conveyance system is shown in Table 4-1.

TABLE 4-1

Stormwater System Inventory

Structure	Quantity
Catch Basins	195
Open Ditch	19,150 feet
6-inch Pipe	2,070 feet
8-inch Pipe	13,280 feet
10-inch Pipe	205 feet
12-inch Pipe	8,300 feet
15-inch Pipe	4,660 feet
18-inch Pipe	3,970 feet
24-inch Pipe	5,330 feet
30-inch Pipe	215 feet
36-inch Pipe	1,010 feet

A hydraulic model of the drainage system was prepared in 1997. Information included in the 1997 inventory was used to model the flow of stormwater through the drainage system. The complete facility inventory used in the hydraulic model is included in Appendix B. The hydraulic modeling of the storm drainage system was used to determine the adequacy of the existing conveyance facilities under various design storm flow regimes and to identify system deficiencies. A system element such as a pipe may be satisfactory for the conveyance of runoff from a 2-year storm, but may not be able to convey the runoff from a 25-year storm. The ability of stormwater systems to convey runoff from specific storm events is a factor used to establish priorities of projects in the capital improvement program.

A significant part of the modeling effort was model verification and calibration in which flows predicted by the model were compared to field measured flows. The model was calibrated by adjusting the runoff parameters to match field measurements. Flow measurements and precipitation data collected in December 1997 was used for model calibration.

4.2 DRAINAGE SYSTEM INVENTORY FOR MODEL

Each major drainage basin, was modeled separately, since, each has its own outfall into either another basin or into Friday Harbor. The portion of Basin 3, tributary to the Port of Friday Harbor detention pond was modeled to determine adequacy of the pond. Only the major trunk lines were modeled. Most of the major trunk lines consist of 12-inch or larger pipes, however, because most of the major lines have a mixture of pipe sizes and ditches, some smaller lines (8-inch) were included. The intent was to analyze the major conveyance components and identify areas which may be inadequate to convey the 2 and 25-year storms. Inventory tables for each basin are included in this chapter which show only the components that were analyzed in the modeling effort. Below is a brief summary of the flow pattern of each basin, and an inventory of the components of the system which were modeled in 1997.

4.2.1 DRAINAGE BASIN NO. 1

Drainage Basin No. 1 is drained by a single system of pipes and ditches that runs from the south side of Grover Street, down through the storage facility. The system begins at the elementary school play fields and runs north to Malcolm Street and turns west. From this point it continues past the vacated right-of-way formerly known as George Avenue, then turns north and runs through the self-storage facility property to the intersection of Web and “A” Streets. At this point, the system flows into the drainage network for Basin No. 2. Table 4-2 shows a list of the system’s components included in the model.

TABLE 4-2

Drainage Basin No. 1 Stormwater System Inventory

Structure	Quantity
Catch Basins	8
Open Ditch	910 feet
8-inch Pipe	55 feet
12-inch Pipe	185 feet
18-inch Pipe	880 feet

4.2.2 DRAINAGE BASIN NO. 2

Drainage Basin No. 2 has a pipe and ditch stormwater conveyance system that transports runoff from the south end of Hunt Street to Nichols Street and into Friday Harbor. For the model, flow was routed directly into the culvert which crosses Hunt Street at the intersection with Nelson Street. The system then transports runoff down Nelson Street, north on Linder Street, and then west on Franck Street and north on “C” Street to Nichols Street. At the intersection of Web and “A” Streets a 12-inch pipe conveys runoff from Basin No. 1 into the system. Flow is routed through a 12-inch pipe to Sunshine Alley and into Friday Harbor. Table 4-3 shows a list of the system’s components included in the model.

TABLE 4-3

Drainage Basin No. 2 Stormwater System Inventory

Structure	Quantity
Catch Basins	7
Open Ditch	1,140 feet
8-inch Pipe	640 feet
12-inch Pipe	1,450 feet

4.2.3 DRAINAGE BASIN NO. 3

The Town has annexed the northern portion of the Friday Harbor Airport since the time the hydraulic model was developed. The annexation area is also in Drainage Basin No. 3. Drainage Basin No. 3 is a sub-basin of the North Bay Drainage Basin.

Drainage Basin No. 3 includes the southern most portions of town and drains south into North Bay. There are four subbasins, each with ditch and/or pipe systems, which convey runoff into a detention pond owned by the Port of Friday Harbor and ultimately into North Bay and one sub-basin which drains to the west to Argyle Avenue and then south into San Juan County and also into North Bay.

The eastern most drainage subbasin is tributary to the wetland identified in the Town's Critical Area ordinance as Wetland F260. Drainage from the north and east enters the wetland though the detention pond at Rose Lane. Discharge from the wetland outlets to the south via a 15-inch culvert located under the Browns Home Center. The discharged drainage continues southeast until it reaches the detention pond owned by the Port of Friday Harbor. The detention pond is east of Mullis Street and north of Argyle Road. This subbasin contains 8-inch and 12-inch diameter pipe in Argyle Avenue and Rose Lane.

Drainage conveyance for the sub-basin, which consists of areas draining to Mullis Road, includes a road ditch on the east side of Mullis Street. Drainage is directed south via a ditch, with 12-inch culverts conveying flow under driveways, to a 22" x 18" grated stormwater inlet where the flow is directed east long the road ditch on the north side of Argyle Road via a 30-inch culvert. Flow in this ditch continues east eventually discharging to the Port of Friday Harbor detention pond.

The subbasin which lies west of Mullis Street and north of the Friday Harbor Airport drains through 8-inch diameter pipes and open ditches to the airport. Drainage from the subbasin that includes the Friday Harbor Airport is conveyed through pipes and ditches to the Port of Friday Harbor detention pond.

Discharge from the detention pond is conveyed to North Bay via a series of pipes, ditches, and man-made ponds.

4.2.4 DRAINAGE BASIN NO. 4

Drainage Basin No. 4 conveys stormwater through a main trunk line along Spring Street to Friday Harbor. Two main side laterals enter the system at Argyle Avenue and at Second Street. The western and central parts of the basin flow into the system at various points along Spring Street. The main line along Argyle Avenue begins just south of John Street. The other main lateral starts through an 8-inch culvert at the intersection of Price and Park Streets and flows along Park Street and Reed Street, and then turns southwest down Second Street to Spring Street. Table 4-4 shows a list of the system's components included in the model.

TABLE 4-4

Drainage Basin No. 4 Stormwater System Inventory

Structure	Quantity
Catch Basins	48
Open Ditch	400 feet
8-inch Pipe	1,425 feet
12-inch Pipe	924 feet
15-inch Pipe	3,089 feet
18-inch Pipe	1,380 feet
24-inch Pipe	1,045 feet
30-inch Pipe	90 feet
36-inch Pipe	360 feet

4.2.5 DRAINAGE BASIN NO. 5

Drainage Basin No. 5 collects runoff in several catch basins in downtown and conveys stormwater through 8- and 12-inch pipes into Friday Harbor. For the model, all the flow from this basin was routed through a single 12-inch line which runs down Spring Street into the harbor. Table 4-5 shows a list of the system's components included in the model.

TABLE 4-5

Drainage Basin No. 5 Stormwater System Inventory

Structure	Quantity
Catch Basins	1
12-inch Pipe	370 feet

4.2.6 DRAINAGE BASIN NO. 6

Drainage Basin No. 6 picks up surface flow from roadside ditches on Harbor View Place, Guard Street, and Marguerite Place. Runoff is conveyed from the Guard/Park Street intersection down Guard Street, past Marguerite Place where it then crosses under Guard Street and daylights near an apartment complex inside Basin No. 7. The runoff continues to flow overland from this point into the conveyance system for Basin No. 7 at the intersection of Harbor Street and Tucker Avenue, near the Town's wastewater treatment plant. Table 4-6 shows a list of the system's components included in the model.

TABLE 4-6

Drainage Basin No. 6 Stormwater System Inventory

Structure	Quantity
Catch Basins	2
Open Ditch	1,130 feet
8-inch Pipe	905 feet

4.2.7 DRAINAGE BASIN NO. 7

The stormwater collection system for Drainage Basin No. 7 is the largest system in the Town. It transports runoff from the northern and western portions of the Town to an outfall into the harbor, just north of McDonald Street. This system has four main lines which transport runoff along Carter Avenue, Harbor Street, Guard Street, and Tucker Avenue, in addition to collecting the runoff from Basin No. 6. The system is a mixture of ditches and several sizes of pipe, ranging in size from 8- to 36-inch. Runoff from the west is collected along Carter Avenue and conveyed through ditches behind the homes on Harbor Street to Tucker Avenue. Runoff is also collected at Tucker Avenue and Guard Street and transported to the outfall. Runoff from the northeast part of Town is collected at Marble Street and Larson Street and transported through ditches and pipes to the outfall. Table 4-7 shows a list of the system's components included in the model.

TABLE 4-7

Drainage Basin No. 7 Stormwater System Inventory

Structure	Quantity
Catch Basins	15
Open Ditch	2,900 feet
8-inch Pipe	180 feet
12-inch Pipe	415 feet
18-inch Pipe	160 feet
24-inch Pipe	1,593 feet
30-inch Pipe	201 feet
36-inch Pipe	530 feet

4.3 HYDROLOGIC/HYDRAULIC MODELING

Hydrologic analysis addresses the relatively short-term movement of water over the land resulting from precipitation. The purpose of a hydrologic model is to determine the flow of stormwater runoff over a period of time passing a specified point. The information generated in the hydrologic model is presented in the form of a hydrograph, a standard plot of runoff (cubic feet per second, cfs) versus time (hours) for a given design storm event.

Hydrograph analysis utilizes the standard plot of runoff versus time for a given design storm allowing the key characteristics of runoff such as peak flow, volume and phasing to be considered in the design of drainage facilities. The physical characteristics of the site and the design storm determine the magnitude, volume, and duration of the hydrograph. Other factors such as the conveyance characteristics of channels or pipes, merging tributary flows, branching channels, and flooding can alter the shape and magnitude of the hydrograph. The key elements of hydrograph analysis are:

- Design storm
- Runoff parameters
- Hydrograph synthesis
- Hydrograph routing
- Hydrograph summation and phasing
- Computer applications

4.3.1 DESIGN STORM

All storm event hydrograph methods require the input of a rainfall distribution or design storm hyetograph. The design storm hyetograph is a plot of rainfall depth versus time for a given design storm frequency and duration. It is usually presented as a dimensionless plot of unit rainfall depth versus time. Design storms are based on:

- Total rainfall (depth in inches).
- Rainfall distribution, specified by return frequency and duration.

The design storm hyetograph is constructed by multiplying the dimensionless hyetograph times the total rainfall depth (in inches) for the design storm. This creates a volume and distribution of rainfall over a given period of time. Figure 4-2 shows the recommended hyetograph used for this model. This hyetograph is the standard SCS Type 1A rainfall distribution for the Puget Sound basin.

The four design storm scenarios which were modeled for Friday Harbor include: the 6-month, 2-year, 25-year, and 100-year 24 hour storm events. The 6-month design storm will be used to design water quality treatment facilities, and the 2-year and 25-year design storms will be used to assist the Town in identifying areas needing improvements. The 25-year event will serve as a maximum design goal for sizing conveyance facilities. The precipitation totals for each design storm event are shown in Table 2-5.

All storm event hydrograph-modeling methods require input of parameters, which describe physical drainage basin characteristics. These parameters provide the basis from which the runoff hydrograph is developed. The three key parameters are surface area, curve number (a value which indicates the relative amount of impervious surface) and time of concentration. The curve numbers were developed by the SCS based on runoff characteristics of the land and are dependent upon the soil type and land use. Time of Concentration, T_C, is the amount of time for water to travel from the hydraulically most distant point in the watershed to the outlet of the watershed.

The proper selection of homogeneous basin areas is required to obtain the highest degree of accuracy in hydrograph analysis. Significant differences in land use within a given drainage basin must be addressed by dividing the basins into sub-basin areas of similar land use and/or runoff characteristics.

The steps required in the development of runoff parameters are:

- Delineate the drainage basins into sub-basins of homogeneous characteristics for each designated discharge point.
- Identify land use and amount of impervious area.
- Identify soil types from SCS survey data, existing information or field surveys.
- Calculate the time of concentration, T_C for each sub-basin.
- Identify existing drainage features and stormwater facilities.

4.3.2 RUNOFF PARAMETERS

4.3.2.1 Drainage Basin Area

The six drainage basins analyzed were delineated into 73 sub-basins, based on land use, topography and location of stormwater conveyance systems. The area of each was determined using a planimeter.

4.3.2.2 CN Values

The Soil Conservation Service (SCS), has conducted studies into the runoff characteristics of various land types. The SCS has developed relationships between land use, soil type, vegetation cover, interception, infiltration, surface storage and runoff. The relationships have been characterized by a single runoff coefficient called a “curve number.” These curve number (CN) values are based on soil type and land use. The combination of these two factors is called the “soil-cover complex.” The soil-cover complex have been assigned to one of four hydrologic soil groups, according to their runoff characteristics. Separate CN values must be selected for the pervious and impervious area of an urban basin.

4.3.2.3 T_C Values

The value of T_c is dependent upon the slope, soil type and vegetation cover of the area under study. T_c can be calculated by summing consecutive travel times across the sub-basins. Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow or some combination of these. The type of flow that occurs is best determined by field inspection.

Sheet flow is flow over plane surfaces. It usually occurs in the headwaters of streams. With sheet flow, the friction value n_s (from Manning's roughness coefficient) is used. These n_s values are for very shallow flow and should be used only for travel lengths up to 300 feet. Manning's kinematic solution can be used directly to compute travel time, T_t for the first 300 feet:

$$T_t = \frac{0.42(n_s L)^{0.8}}{(P_2)^{0.527}(s_o)^{0.4}}$$

where:

T_t	=	travel time (min)
n_s	=	Manning's roughness coefficient for sheet flow
L	=	flow length (ft)
P_2	=	2-year, 24 hour rainfall (= 1.5 inches for Friday Harbor), and
s_o	=	slope of hydraulic gradient (ft/ft)

After 300 feet, sheet flow is assumed to become shallow concentrated flow. The average velocity (ft/sec) and travel time for this type of flow can be calculated using Manning's velocity factor for shallow concentrated flow, k_s and the slope, s_o of the flow path:

$$V = k(s_o)^{0.5}$$

$$T_t = \frac{L}{60V}$$

Open channel flow can be calculated similarly to shallow concentrated flow with the use of Manning's velocity factors for channels, k_c. T_c can be calculated by summing consecutive travel times across the sub-basins.

Table III-1.4 from the *DOE Stormwater Manual* shows the "n" and "k" values for various surfaces and channels. This table is included in Appendix C.

4.3.3 COMPUTER APPLICATIONS/HYDRA MODEL

Computer models have been developed to speed up the calculation of a stormwater hydrograph. The software used in the analysis of the Town of Friday Harbor system is HYDRA developed by PIZER, Inc. The method used by HYDRA to develop hydrographs is the SCS-based Santa Barbara Urban Hydrograph (SBUH) method.

HYDRA develops runoff hydrographs from the information input into the model. The model operator must also input information into the model about the stormwater conveyance system which is available to carry the runoff. The hydrographs are then routed through the conveyance system to simulate the flow in the system during various design storm conditions.

The HYDRA stormwater model simulates rain on each land segment which in turn generates a runoff hydrograph that is injected into the conveyance system. Individual hydrographs are merged together to form a system hydrograph which is routed through the system. The model will simulate peak flow, and duration of flow for various storm events and land use scenarios.

The hydraulic/hydrologic model is a tool, which provides a compilation of information which is then used for planning and design. This modeling is useful as an analytical and planning tool for stormwater management decisions. The model can be used as a design tool because the model generates information about the peak flow, volume of flow, duration of flow, and the capacity of the existing system. The model provides an analysis to describe the cumulative effects of runoff from several basins having different drainage characteristics.

The following tasks were completed to model the Town's system:

1) The Town's stormwater conveyance system was field checked with pipe and ditch locations, lengths, invert elevations and pipe sizes and verified by the Town staff. This information was then put on a base map of the Town.

2) Using a topographic map, with four foot contours, the Town was divided into six main drainage basins which drain into Friday Harbor. The basins were defined according to the trunk line(s) that collected the runoff. A seventh basin was defined which drains to the south into North Bay.

3) Again using the topographic map, the main drainage basins were divided into smaller sub-basins according to the land use within each area. A total of 73 sub-basins were defined. The sub-basins are shown in Figure 2-4.

4) For each of these sub-basins, the acreage was measured using a planimeter. This data, and the data acquired in Task No. 1 were put into an Excel/dBase database in the format required by HYDRA.

5) The times of concentration were calculated using the methods and tables of data outlined in the Department of Ecology's *Stormwater Manual for the Puget Sound*, aerial photos of the Town and the Soil Survey for San Juan County. This information was then put into the HYDRA command files. The details and calculation of these parameters is included in Appendix D.

6) The percentage of impervious surface was calculated using aerial photos. Housing density (dwelling units per acre, du/acre) for residential areas was estimated and values for percent impervious were chosen from Table III-1.3 of the DOE manual. Commercial and industrial areas were chosen to be 100 percent impervious. Table III-1.3 can be found in Appendix E.

7) Most of the soils in the Town belong to Hydrologic Soil Group D with low infiltration rates, with some areas belonging to Soil Group A which are excessively drained with very high infiltration rates. If an area has more than one type, the dominant soil type was used. Runoff curve numbers were chosen based on the soil types and land use from Table III-1.3 in the DOE manual (Appendix E).

8) The HYDRA model was run for the 6-month, 2-year, 25-year, and 100-year storm events for the existing and future land use conditions at the time the model was prepared. The future land use conditions were defined by aerial photos and the 1994 Draft *Comprehensive Plan* zoning map. Since the time the model was prepared, the 2002 Comprehensive Plan included several zoning changes for specific parcels throughout Town. Figure 2-11 shows the land use used to hydraulic model of current conditions (from the 1994 Draft *Comprehensive Plan)*. The 1994 zoning map was used to develop future land use information when the model was prepared. Figure 2-12 shows the current zoning map. The 1994 zoning map and the 2004 zoning map were compared to determine whether the future land use conditions used in the 1997 hydraulic model were still relevant.

   A significant increase in the amount of impervious surface within the basin or subbasin may have an impact on the hydraulic analysis. Several assumptions regarding the amount of impervious cover of specific land uses were made to build the model. Commercial professional services and industrial land uses were assumed to be 100 percent impervious. Single-family residential was assumed to range from 42- to 53-percent impervious depending on the number of dwelling units per acre.

   The majority of the zoning changes from the 1994 zoning map to the 2004 zoning map involved the change in designation between commercial, industrial, and professional uses. Changes between these land uses have no consequence for the model results since all categories were assumed to be 100 percent impervious. The other zoning changes included changes from commercial or professional to multi-family and multi-family to commercial or professional. Either of those changes would not have significant impact on the model since all of these land uses were assumed to have a high percentage of impervious coverage.

The zoning changes that could have more impact on the model results are changes from single family designation to multi-family, commercial, professional services, or industrial. The actual impact on conveyance system capacity is mitigated since all development other than single-family units developed individually must provide on-site detention. Although some zoning changes have been made throughout Friday Harbor the results of the 1997 hydraulic model are still relevant.

Tables 4-8 and 4-9 show the subbasins and the runoff parameters calculated for each existing and future land use area. The calculation of land use areas developed for the model are included in Appendix D.

TABLE 4-8

Runoff Parameters – Existing Land Use (from Hydraulic Model - 1997 Stormwater Management Plan)

Basin	Sub-Basin	Acreage	Time of Concentration	% Impervious	CN for Pervious	Notes
1.	1	14.72	44.18	25	90	Elementary school with grass playfields
	2	3.50	91.74	0	81	Woods
	3	9.60	69.55	0	86	Woods and pasture
	4A	5.99	62.27	14	83	Woods with wooded residential lots
	5	3.58	90.74	0	81	Woods
	8	13.60	31.65	15	91	Storage facility – mostly impervious with grass
2.	6A	6.67	56.75	18	85	Woods and residential
	6B	2.75	44.73	0	86	Woods and brush
	7	7.57	115.71	23	51	Woods and residential
	9	6.60	35.54	19	61	Mixture of pasture, brush and residential
	10	6.06	54.31	22	68	Residential
	11A	2.53	3.76	100	n/a	Commercial with some residential
	11B	2.53	5.38	100	n/a	Commercial with some residential
	12	5.24	26.72	52	67	Commercial, residential and pastures
	13	7.03	36.87	26	63	Residential with some woods
	14	4.27	4.96	100	n/a	Commercial
3.	15	11.47	n/a	n/a	n/a	This sub-basin drains into North Bay.
	16	11.20	n/a	n/a	n/a	This sub-basin drains into North Bay.
	17	14.75	n/a	n/a	n/a	This sub-basin drains into North Bay.
	18	15.60	n/a	n/a	n/a	This sub-basin drains into North Bay.
	19	8.05	n/a	n/a	n/a	This sub-basin drains into North Bay.
	21	8.34	n/a	n/a	n/a	This sub-basin drains into North Bay.
	22	13.00	n/a	n/a	n/a	This sub-basin drains into North Bay.

TABLE 4-8

Runoff Parameters – Existing Land Use (from Hydraulic Model - 1997 Stormwater Management Plan)

Basin	Sub-Basin	Acreage	Time of Concentration	% Impervious	CN for Pervious	Notes
4.	4B	3.73	28.00	21	76	Residential, wooded lots
	20	2.88	94.25	0	84	Woods and brush
	23	9.52	30.67	20	86	Woods, brush and impervious
	24	7.75	83.81	10	87	Woods, brush, grass and impervious
	25	8.94	83.06	16	88	Brush and residential
	26	7.13	43.83	25	87	Woods, residential, grass and impervious
	27	6.39	35.12	15	89	Pasture, residential and woods
	28	12.77	18.05	60	83	Commercial, pasture and woods
	29	6.93	25.31	85	90	Commercial with some grass
	31	9.19	27.70	37	90	Residential, pasture and some impervious
	32	10.25	26.50	34	90	Residential, pasture and some impervious
	33A	6.36	4.07	100	n/a	Commercial
	33B	6.36	4.58	100	n/a	Commercial
	34	3.71	6.04	100	n/a	Commercial
	35	2.51	26.10	46	90	Residential and professional
	39	4.60	6.69	70	90	Commercial and grass
5.	36	6.17	3.83	100	n/a	Commercial
6.	30	6.96	30.25	25	87	Residential and woods
	38	1.06	58.30	48	86	Residential
	40	5.61	97.22	21	86	Residential, woods and brush
	41	1.50	33.99	8	83	Woods and residential
	42	4.28	82.05	10	87	Woods with some impervious
	43	8.99	35.68	48	90	Residential and commercial
	46A	7.55	71.14	18	87	Woods, brush and residential

TABLE 4-8

Runoff Parameters – Existing Land Use (from Hydraulic Model - 1997 Stormwater Management Plan)

Basin	Sub-Basin	Acreage	Time of Concentration	% Impervious	CN for Pervious	Notes
7.	44	4.67	39.11	37	89	Residential, woods, brush and impervious
	45	14.14	39.34	50	90	High school with football field, etc.
	46B	7.56	94.27	10	86	Woods, brush and impervious
	47	4.62	4.27	100	20	Commercial
	48	12.92	31.97	42	90	Residential, commercial and some brush
	49	15.49	20.91	25	90	Pasture and commercial
	50	9.27	11.34	40	89	Residential with woods and commercial
	51A	18.40	85.51	10	86	Woods and brush with some impervious
	51B	10.80	97.89	10	86	Brush and commercial
	52	3.64	19.73	50	86	Brush and commercial
	53	15.24	13.83	20	89	Pasture, brush and commercial
	54	5.33	6.13	70	90	Commercial, brush and grass
	55	13.44	52.06	31	90	Residential pasture and impervious
	56	8.09	25.94	21	90	Residential and pasture
	57	8.15	53.47	0	89	Pasture
	58	11.20	99.42	0	86	Woods
	59A	6.70	79.19	0	88	Woods and pasture
	59B	12.80	71.30	0	88	Woods and pasture
	60	16.75	88.24	5	88	Pasture with woods
	61	21.95	30.70	30	87	Brush, mobile homes and pasture
	62	23.99	34.69	31	88	Brush, mobile homes and pasture
	63	7.32	44.75	20	87	Brush, pasture, woods and impervious
	64	5.77	46.08	13	87	Woods and residential
	65	6.70	9.95	30	89	Pasture and gravel
	66	6.45	49.97	10	86	Woods with some residential

TABLE 4-9

Runoff Parameters – Future Land Use (from Hydraulic Model – 1997 Stormwater Management Plan)

Basin	Sub-Basin	Acreage	Time of Concentration	% Impervious	CN for Pervious	Notes
1.	1	14.72	44.18	35	90	Elementary school with grass playfields/some residential
	2	3.50	25.89	42	81	Residential 4.0 du/acre
	3	9.60	19.06	71	86	Residential 4.0, multi-family and commercial
	4A	5.99	16.43	66	87	Residential 4.0 and multi-family
	5	3.58	25.89	42	81	Residential 4.0 du/acre
	8	13.60	4.74	100	91	All commercial
2.	6A	6.67	27.78	36	85	Residential 3.3 du/acre
	6B	2.75	21.04	42	86	Residential 4.0 du/acre
	7	7.57	32.99	42	51	Residential 4.0 du/acre
	9	6.60	4.05	95	61	Commercial and multi-family
	10	6.06	26.80	22	68	Residential 1.7 du/acre
	11A	2.53	3.76	100	n/a	Commercial
	11B	2.53	5.38	100	n/a	Commercial
	12	5.24	25.41	72	67	Residential 5.0 and commercial
	13	7.03	36.87	30	63	Residential 2.5 du/acre
	14	4.27	4.96	100	n/a	Commercial
3.	15	11.47	n/a	n/a	n/a	This sub-basin drains south into North Bay.
	16	11.20	n/a	n/a	n/a	This sub-basin drains south into North Bay.
	17	14.75	n/a	n/a	n/a	This sub-basin drains south into North Bay.
	18	15.60	n/a	n/a	n/a	This sub-basin drains south into North Bay.
	19	8.05	n/a	n/a	n/a	This sub-basin drains south into North Bay.
	21	8.34	n/a	n/a	n/a	This sub-basin drains south into North Bay.
	22	13.00	n/a	n/a	n/a	This sub-basin drains south into North Bay.

TABLE 4-9 – (continued)

Runoff Parameters – Future Land Use (from Hydraulic Model – 1997 Stormwater Management Plan)

Basin	Sub-Basin	Acreage	Time of Concentration	% Impervious	CN for Pervious	Notes
	4B	3.73	22.19	53	76	Residential 3.0 du/acre and multi-family
	20	2.88	42.99	42	84	Residential 4.0 du/acre
	23	9.52	8.93	100	86	Professional and commercial
	24	7.75	7.11	96	87	Industrial, professional and multi-family
	25	8.94	20.22	62	88	Residential 2.2, industrial and multi-family
	26	7.13	19.30	75	87	Residential 2.0, commercial and multi-family
	27	6.39	15.46	92	89	Commercial with some residential 4.0 and multi-family
	28	12.77	5.15	85	83	Professional, commercial and residential 4.0
	29	6.93	4.60	100	90	Commercial
	31	9.19	7.48	51	90	Residential 3.0 and commercial
	32	10.25	8.08	59	90	Residential 2.3, commercial, professional and multi-family
	33A	6.36	4.07	100	n/a	Commercial and professional
	33B	6.36	4.58	100	n/a	Commercial and professional
	34	3.71	6.04	100	n/a	Commercial
	35	2.51	3.31	100	90	Commercial and professional
	39	4.60	6.69	100	90	Commercial
4.	36	6.17	3.83	100	n/a	Commercial
5.	30	6.96	17.94	47	87	Residential 3.3 and professional
	38	1.06	58.30	48	86	Residential 5.0 du/acre
	40	5.61	27.09	21	86	Residential 2.5 du/acre
	41	1.50	33.99	34	83	Residential 3.0 du/acre
	42	4.28	21.58	58	87	Residential 2.0 and multi-family
	43	8.99	35.68	48	90	Residential 2.0 and multi-family
	46A	7.55	33.50	34	87	Residential 3.0 du/acre
	44	4.67	28.80	34	89	Residential 3.0 du/acre

TABLE 4-9 – (continued)

Runoff Parameters – Future Land Use (from Hydraulic Model – 1997 Stormwater Management Plan)

Basin	Sub-Basin	Acreage	Time of Concentration	% Impervious	CN for Pervious	Notes
	45	14.14	35.90	58	90	High school with football field, residential 4.0
	46B	7.56	45.33	42	86	Residential 4.0 du/acre
	47	4.62	4.27	100	20	Commercial and industrial
	48	12.92	4.62	74	90	Residential 2.7, industrial and multi-family
	49	15.49	3.89	92	90	Multi-family and commercial
	50	9.27	9.42	60	89	Residential 3.0, commercial and professional
	51A	18.40	74.21	8	86	Residential 4.0 with woods outside Town Limits
	51B	10.80	93.59	10	86	Outside Town Limits
	52	3.64	8.43	100	86	Industrial
	53	15.24	6.19	88	89	Industrial, commercial, residential, professional, multi-family
	54	5.33	4.51	94	90	Multi-family, commercial, professional, and industrial
	55	13.44	37.35	34	90	Residential 3.0 du/acre
	56	8.09	25.94	34	90	Residential 3.0 du/acre
	57	8.15	49.17	42	89	Residential 4.0 du/acre
	58	11.20	70.11	42	86	Residential 4.0 du/acre
	59A	6.70	61.81	42	88	Residential 4.0 du/acre
	59B	12.80	34.97	42	88	Residential 4.0 du/acre
	60	16.75	77.68	42	88	Residential 4.0 du/acre
	61	21.95	19.78	51	87	Residential 4.0 and mobile homes
	62	23.99	18.43	52	88	Residential 4.0 and mobile homes
	63	7.32	4.0	90	87	Mutli-family
	64	5.77	4.26	90	87	Mutli-family
	65	6.70	9.95	30	89	Pasture and gravel – outside Town Limits
	66	6.45	5.14	90	86	Multi-family

4.3.4 MODEL CALIBRATION/VERIFICATION

A computer model is only as accurate as the input data. It is necessary to make assumptions for the system as input; but field data must be used to calibrate the model. The validation of the model's performance can be evaluated by three methods. First, the flows generated by the model can be compared to flows and rainfall measured in the field. Second, the model results can be compared to previous studies and models. Third, in general, the model results can be compared with known conditions, such as areas that periodically flood.

When calibrating the model based on the above comparisons, several parameters can be adjusted. The first parameter is the percentage of impervious area. Because rough estimations were obtained from aerial photographs it is expected that these percentages may need to be adjusted.

The second parameter which is normally adjusted is the time of concentration calculations. The availability of a topographic map with a 4-foot contour interval provided sufficient detail to determine an estimate of the travel distance and ground slope. These two variables together with the velocity factor "k" (roughness dependent upon land use) determine the time of concentration. Using the topographical map and aerial photos, a good estimate for time of concentration was obtained.

The third parameter which has an impact upon the model's accuracy is the SCS curve numbers (CN). This number controls the amount of runoff from the pervious areas and is dependent on soil type, compaction of the soil and vegetation cover. A soils map and aerial photos were available and were used to estimate the curve numbers.

4.4 MODEL RESULTS

The following paragraphs describe the model results for current and future land use as defined in the 1997 Stormwater Management Plan. As discussed in Section 4.3.3, the model is relevant under the existing Town zone designation.

Figure 4-3 illustrates areas of deficient capacity as identified by the model results for the 2-year and 25-year storm events for existing and future conditions. In general, the ditches which are located around town appear to have adequate capacity, but several 8 and 12-inch sections of pipe do not. Specific results of the modeling effort are included in Appendix G. Each of the Drainage Basins will be discussed separately. The segment designations which appear in the following tables refer to the pipe or ditch designation which can be found in the system inventory in Appendix B.

4.4.1 DRAINAGE BASIN NO. 1 MODEL RESULTS

Drainage Basin No. 1 is a small basin located in the southeastern portion of town from south of the elementary school to the storage facility. The basin drains predominantly north towards Friday Harbor and flows into the conveyance system for Drainage Basin No. 2 at the intersection of Web and “A” Streets. This piping/ditch system is adequate for the 2-year storm for existing development conditions. The model identified sections of pipe on Malcolm Street which were not adequate to convey the 25-year storm for existing conditions. The segment designation, existing capacity, and modeled runoff for the existing and future conditions for the deficient system segments are shown in Table 4-10. The Town completed a major drainage project in 1999 that addressed these deficiencies.

TABLE 4-10

Drainage Basin No. 1 System Deficiencies

		Existing			Future		
Segment/Size/Location	**Existing Capacity (CFS)**	**Runoff 6-Mo. Storm (CFS)**	**Runoff 2-yr. Storm (CFS)**	**Runoff 25-yr. Storm (CFS)**	**Runoff 6-mo. Storm (CFS)**	**Runoff 2-yr. Storm (CFS)**	**Runoff 25-yr. Storm (CFS)**
BLU1006 (18) Malcolm	6.39	0.81	2.19	7.62	2.13	4.00	10.95
BLU1008 (12) Malcolm	2.61	0.81	2.19	7.62	2.13	4.00	10.95
BLU1009 (8) Malcolm	2.17	0.90	2.46	8.80	2.78	5.21	13.93
BLU1010 (ditch-1x1) Storage	4.96	0.90	2.46	8.80	2.78	5.21	13.93
BLU1011 (ditch-3x2) Storage	43.00	1.65	4.25	14.03	5.18	9.85	23.68

4.4.2 DRAINAGE BASIN NO. 2 MODEL RESULTS

Drainage Basin No. 2 is a basin located east of Drainage Basin No. 1. Runoff travels from the south end of Hunt Street along Nelson Street, Linder Street, Nichols Street and Sunshine Alley into Friday Harbor. This system picks up flow from Basin No. 1 at the intersection of Web and "A" Streets. This ditch/pipe system is inadequate to convey the 2-year storm in some sections. The 12-inch pipes along Nichols Street and Sunshine Alley are also significantly undersized for the 25-year storm. The segment designation, existing capacity and modeled runoff for the existing and future conditions for the deficient system segments are shown in Table 4-11.

TABLE 4-11

Drainage Basin No. 2 System Deficiencies

Segment/Size/Location	Existing Capacity (CFS)	Existing			Future		
		Runoff 6-Mo. Storm (CFS)	Runoff 2-yr. Storm (CFS)	Runoff 25-yr. Storm (CFS)	Runoff 6-mo. Storm (CFS)	Runoff 2-yr. Storm (CFS)	Runoff 25-yr. Storm (CFS)
ORG1003 (8) Nelson	2.563	0.28	0.66	2.08	0.80	1.41	3.85
ORG1004 (8) Linder	0.66	0.45	1.05	3.42	1.18	2.10	5.79
ORG1007 (12) "A"	4.39	1.65	4.25	14.03	1.65	9.85	23.68
ORG1008 (12) Nichols	1.66	3.37	7.48	22.21	5.42	16.37	39.04
ORG1009 (12) Sunshine	5.42	4.75	9.80	27.10	6.80	18.70	43.94

4.4.3 DRAINAGE BASIN NO. 3 MODEL RESULTS

The eastern three (3) sub-basins of Drainage Basin No. 3 drain to the Port of Friday Harbor detention pond located east of Mullis Road and north of Argyle Road. The detention pond was created in 1985 to manage runoff from the airport property. The pond was expanded in the late 1980’s to provide additional detention volume for full development of upstream land within the watershed. The pond was designed to detain the stormwater peak rate of runoff from the 50-year, 24-hour storm event in the developed condition to the corresponding peak rate of runoff in the undeveloped condition.

The detention pond sizing was reevaluated by MDP, Inc., the Port of Friday Harbor engineers, in 1999. Per MDP, the original basin draining to the detention pond has been decreased due to diversion of a significant portion of the airport drainage south to Mill Street. MDP (Tom Metke, personal communication, December 2000) estimated that 60 percent of the tributary basin had been diverted away from the detention pond. The MDP re-evaluation concluded that the pond had adequate capacity to detain projected stormwater runoff for the basin currently contributing to the pond for the 50-year event and release it at the pre-development rate of 20.14 cfs. (Note; the pre-development tributary flow of 20.14 cfs was determined based on 189 acres tributary area).

The Town of Friday Harbor’s policy is for new development to provide detention for the 10-year, 24-hour and 100-year, 24-hour peak stormwater flows. The existing detention pond was evaluated to determine if the pond would be adequate to provide this level of detention for new development within Basin 3. The analysis assumed that 60 percent of the original airport area was no longer routed to the detention pond and the areas within the Town limits were fully developed. The analysis also assumed the existing single orifice outlet control structure was replaced with a multiple orifice structure, which would allow metering of peak flows from several storm events.

San Juan County prepared a drainage study for the North Bay drainage basin (*North Bay Drainage Basin Study*, 2002, Gray & Osborne, Inc.). Drainage Basin No. 3, including the recently annexed portion of the Friday Harbor airport, is located in the North Bay basin. The *North Bay Drainage Basin Study* included the preparation of a hydraulic model of the conveyance system and detention pond in the basin. The results of the model indicated that the Mullis Street conveyance system upstream of the detention pond are generally adequate to convey flows for the 100-year, 24-hour design storm with the exception of the catch basin located at the northwest corner of the intersection of Mullis Street and Argyle Avenue and the ditch immediately upstream of the port detention pond. The conveyance system on Argyle Avenue was also adequate to convey the modeled flows from the tributary areas. The capacity of the Port detention pond is inadequate to detain the 100-year, 24-hour flows. The modeled discharge from the detention pond during a 100-year, 24-hour event was 64.6 cfs. The capacity of the downstream conveyance system, a series of small diameter pipe and small ponds on private property, is limited to 4 cfs.

A new downstream conveyance system located in the existing ditch on the north side of Argyle Avenue was recommended in the *North Bay Drainage Basin Study* to provide adequate capacity from the detention pond to North Bay. In addition to the downstream conveyance system improvements the *North Bay Drainage Basin Study* included recommendations for improvements to the detention pond control structure to provide water quality storage in the pond and to direct discharge from the pond to the new conveyance system.

It appears from the analysis that there is not additional capacity available in the Port detention pond to accommodate stormwater flows from new development or redevelopment in Basin 3 to meet the Town's standards. The Town requires that new development or redevelopment provide detention onsite for the 10-year, 24-hour, and 100-year, 24-hour storm events. This recommendation is similar to the recommended detention requirements for the other basins in Town.

4.4.4 DRAINAGE BASIN NO. 4 MODEL RESULTS

Basin No. 4 drains the central portions of town west of Argyle Avenue and north of Spring Street. This basin is much larger than Basins No. 1 and No. 2, and has several areas which are inadequate to convey the 2-year storm, and several more which cannot convey the 25-year storm. The segment designation, existing capacity and modeled runoff for the existing and future conditions for the deficient system segments are shown in Table 4-12 (revised 9/11/2000).

TABLE 4-12

Drainage Basin No. 4 System Deficiencies

Segment/Size/Location	Existing Capacity (CFS)	Existing			Future		
		Runoff 6-Mo. Storm (CFS)	Runoff 2-yr. Storm (CFS)	Runoff 25-yr. Storm (CFS)	Runoff 6-mo. Storm (CFS)	Runoff 2-yr. Storm (CFS)	Runoff 25-yr. Storm (CFS)
RED1007(12) Price	3.29	0.26	0.69	2.22	1.05	1.78	3.80
RED1010(8) Spring/Mullis	1.18	0.53	1.42	4.75	2.10	3.61	8.23
RED1018(18) Spring @ Argyle	11.95	3.11	6.00	15.45	5.59	9.50	20.77
RED2006(15) Argyle	4.70	0.32	0.77	2.77	1.24	2.18	5.57
RED2013(15) Spring	5.07	4.79	9.69	26.47	11.62	19.73	43.31
RED3003(8) Park/Price	1.80	0.71	1.50	4.01	0.94	1.59	3.69
RED3004(8) Park/Price	2.11	0.71	1.50	4.01	0.94	1.59	3.69
RED3010(8) Reed	0.60	1.47	3.16	8.51	2.16	3.64	8.29
RED3011(8) Reed	1.67	1.47	3.16	8.51	2.16	3.64	8.29
RED3012(8) Reed	1.47	1.47	3.16	8.51	2.16	3.64	8.29
RED3013(8) Reed	2.14	1.47	3.16	8.51	2.16	3.64	8.29
RED4004(8) Court	1.47	0.73	1.33	3.06	0.93	1.58	3.35
RED4005(8) Court	1.47	0.73	1.33	3.06	0.93	1.58	3.35
RED4007(12) Second	3.16	0.73	1.33	3.06	0.93	1.58	3.35
RED4010(15) Second	10.95	2.43	4.94	12.72	3.60	6.11	13.39
RED4016(15) Second	9.79	2.43	4.94	12.72	3.60	6.11	13.39
RED4017(15) Second	8.27	2.43	4.94	12.72	3.60	6.11	13.39
RED4020(12) Spring	7.21	3.71	7.10	17.27	5.00	8.49	18.43
RED5001(15) Spring	12.08	8.50	16.79	43.74	17.23	29.30	64.00
RED5002(15) Spring	18.35	8.5	16.79	43.74	17.23	29.30	64.00

The 8-inch diameter storm drains on Reed Street have been replaced with 12-inch diameter drains in 1988. Conveyance system improvements on Spring Street from First Street to the Waterfront were installed in 1999.

4.4.5 DRAINAGE BASIN NO. 5 MODEL RESULTS

Basin No. 5 is a very small basin in the downtown area. It encompasses the area between Court and Spring Streets and Second and Front Streets. The drainage system consists of 8 and 12 inch pipes which drain into Friday Harbor. This system has the capacity to convey the 100-year storm.

4.4.6 DRAINAGE BASIN NO. 6 MODEL RESULTS

Basin No. 6 is a ditch/pipe network located in the western portion of town. Runoff is conveyed along Guard Street and Marguerite Place. It ultimately flows into Basin No. 7 northwest of the high school at Guard Street. The 8-inch culverts and pipes in this system are adequate to convey the 2-year storm. They, however, are not capable of conveying the 25-year storm. The segment designation, existing capacity and modeled runoff for the existing and future conditions for the deficient system segments are shown in Table 4-13.

TABLE 4-13

Drainage Basin No. 6 System Deficiencies

		Existing			Future		
Segment/Size/Location	**Existing Capacity (CFS)**	**Runoff 6-mo. Storm (CFS)**	**Runoff 2-yr. Storm (CFS)**	**Runoff 25-yr. Storm (CFS)**	**Runoff 6-mo. Storm (CFS)**	**Runoff 2-yr. Storm (CFS)**	**Runoff 25-yr. Storm (CFS)**
PUR1001 (8) Guard/Park	1.29	0.30	0.81	2.92	0.53	0.96	3.16
PUR1003 (8) Guard/Marg	0.79	0.37	1.04	3.79	0.93	1.65	4.69
PUR1004 (8) Marg	1.04	0.31	0.79	2.49	0.56	0.95	2.50
PUR1006 (8) Marg	1.34	0.31	0.79	2.49	0.56	0.95	2.50
PUR1008 (8) Guard	2.33	1.37	3.20	9.82	2.13	3.68	9.67
PUR1009 (8) Guard	2.08	1.37	3.20	9.82	2.13	3.68	9.67

Since the preparation of the 1997 Plan, a piped drainage system has been installed along Guard Street from approximately Marguerite Place to the 24-inch pipe at Guard and Tucker. This installation has alleviated drainage and flooding problems in the area northwest of the High School.

4.4.7 DRAINAGE BASIN NO. 7 MODEL RESULTS

Basin No. 7 is the largest basin in the Town. Runoff is collected from all the areas north of Park Street and conveyed through pipes and ditches of various sizes into Friday Harbor. The outfall for this basin is north of Harbor Street. One culvert on Carter Avenue is not adequate to convey the 2-year storm event. Several sections are inadequate to convey the 25-year storm. The segment designation, existing capacity and modeled runoff for the existing and future conditions for the deficient system segments are shown in Table 4-14.

TABLE 4-14

Drainage Basin No. 7 System Deficiencies

Segment/Size/Location	Existing Capacity (CFS)	Existing			Future		
		Runoff 6-mo. Storm (CFS)	Runoff 2-yr. Storm (CFS)	Runoff 25-yr. Storm (CFS)	Runoff 6-mo. Storm (CFS)	Runoff 2-yr. Storm (CFS)	Runoff 25-yr. Storm (CFS)
GRN2004 (12) Terra Bella	2.37	1.31	4.36	16.43	2.92	5.16	14.42
GRN2005 (2x2) Carter	13.00	1.31	4.36	16.43	2.92	5.16	14.42
GRN2006 (12) Carter	2.50	3.10	8.28	27.32	6.65	11.45	27.84
GRN2008 (24) Harbor	22.85	5.17	13.58	44.22	10.06	17.36	42.53
GRN2010 (24) Harbor	37.68	5.17	13.58	44.22	10.06	17.36	42.53
GRN4005 (8) Tucker	2.32	1.28	2.97	8.71	2.13	3.61	8.21
GRN4007 (8) Tucker/Marble	2.65	0.82	2.12	6.80	2.99	5.47	12.70
GRN4009A (18) Tucker	15.65	2.10	5.09	15.51	5.01	8.86	20.37
GRN4009 (18) Tucker	18.07	2.10	5.09	15.51	5.01	8.86	20.37
GRN6003(30) Friday	76.54	12.28	29.24	88.07	23.89	41.23	96.21
GRN6004(24) Friday	38.92	13.21	31.18	93.22	24.98	43.17	101.14

4.5 TOWN IDENTIFIED STORMWATER PROBLEM AREAS

Prior to completion of the 1997 Stormwater Management Plan, the Town identified two specific areas of drainage problems. The two areas were designated as a high priority for improvements due to the potential loss from flooding. The first area of concern was south of the self-storage facility on Malcolm Street. The conveyance system dead ended in the middle of the self-storage facility property and traveled overland to "A" and Web Streets. Flooding on the self-storage facility property and in Malcolm Street had been experienced several times during typical storms. The problem had been exacerbated by the development of the new elementary school south of Grover Street. To transport runoff from the school, an 18-inch pipe was installed and connected to the conveyance system at Malcolm Street.

Flooding had also been a problem at the junction of the collection systems for Basins No. 1 and No. 2. The 12-inch pipes running along Nichols Street and Sunshine Alley did not have adequate capacity to convey runoff from the 2-year storm. This problem would become worse if runoff was successfully conveyed around the self-storage facility and into the conveyance system on "A" and Web Streets. The results of the hydraulic model verified this situation. Recommendations to correct this problem were developed. A project to correct these two problem areas was completed in 1999.

The second area of concern was regarding overland flow of runoff through private properties north of Guard Street to the area near the Wastewater Treatment Plant. The ditch/pipe network along Marguerite Place and Guard Street collected runoff from the western parts of town and outfalls onto private property north of Guard Street. This runoff traveled overland across several properties, causing localized flooding. The Town had expressed a desire to run a pipe from this culvert down Guard Street into the conveyance system at Guard and Tucker Streets. New piping was installed in 1998 on Guard Street to direct stormwater runoff east on Guard Street to Tucker Avenue.

Additional stormwater problems areas identified by Town staff include several areas in Basin 7, including, the alignment of the discharge from the Village Grove detention pond, a culvert crossing at Carter Avenue and Larson Street, the ditch and pipe system along Tucker Avenue between Larson Street and approximately McDonald Street. The discharge from the Village Grove detention pond crosses several parcels of private property before entering the drainage system in Larson Street. The Town's staff reported that the culvert crossing at Carter Avenue and Larson Street is not adequately sized to handle the discharge flow from the detention pond at Larson and Carter Streets. Drainage from Carter Street north of Harbor Street discharges to a ditch, which runs through several parcels of private property before discharging into a pipe on private property, and eventually into the Harbor Street conveyance system. The ditch and pipe system on Tucker Avenue south of Larson Street is reportedly too small.

4.6 PREVIOUS HYDRAULIC STUDIES

Three previous hydraulic studies were completed for the Town of Friday Harbor in the 1980's. Krabbe & Starr, Inc. performed two of the studies and Stephen Braun, the other. Krabbe & Starr analyzed the central areas of town in 1983, including the downtown area, and the southeastern portion of town in 1985. Braun analyzed the area of town north of Park Street in 1989. All three studies used the Rational Method to calculate the amount of stormwater runoff. Krabbe & Starr used the rainfall intensity of the 25-year storm and Braun used the rainfall intensity of the 50-year storm. All the studies assumed the land was developed completely under the current zoning ordinances.

The Rational Method is a simple, rough estimate of the runoff based upon an area's size, coefficient of runoff, and the intensity of rainfall. The coefficient of runoff is calculated from the slope of the land and the amount of impervious surface. Based upon a basin's Time of Concentration, a specific rainfall intensity is chosen for that basin. The peak discharge from the basin is then calculated as follows:

$$Q = AiC$$

where

Q = peak discharge, cubic feet per second
A = area, acres
i = rainfall intensity, inches per hour
C = runoff coefficient

As mentioned above, the rational method is a conservative prediction of the amount of runoff from a particular basin. Because of this, the amount of runoff calculated in these studies is significantly higher than that calculated by HYDRA. Specifically, Krabbe & Starr, using the rainfall intensity for the 25-year storm, generated runoff volumes which were 60- to 140-percent higher than those generated from HYDRA in this report. Braun, using the rainfall intensity for the 50-year storm, calculated runoff volumes, which were approximately 200-percent higher than HYDRA's calculations for the 25-year storm event.

TABLE OF CONTENTS

LIST OF TABLES