APPENDIX I: PC-ROUTE OPERATION AND DESIGN EXAMPLE

APPENDIX I – PC-ROUTE SPREADSHEET
Description of Operation and Design Example

1. Introduction

An Excel spreadsheet to route an inflow hydrograph through a storm water detention / retention facility (facility) was developed by the Pima County Regional Flood Control District (District). Basic input to the spreadsheet includes the inflow hydrograph, facility geometry, and outlet structure configuration. The spreadsheet is for general distribution to the consulting community, is titled: **PC-Route**, and is distributed as PC-RouteXX.xls, where XX represents the current version of the spreadsheet. As of this writing, XX is 01. **PC-Route** does not incorporate macros, was developed in Microsoft Excel 2003, and will properly execute in Excel 2007 and Excel 2010. **PC-Route** may be downloaded at: http://rfcd.pima.gov/software/. Currently there is no charge for this spreadsheet. If you encounter programming errors (bugs) while applying **PC-Route**, and / or if you have suggestions to improve **PC-Route**, please direct your correspondence to the District at rfcd@rfcd.pima.gov and enter **PC-Route** in the subject line.

2. Capabilities of PC-Route

PC-Route contains several worksheets (tabs) each dedicated to performing separate routing subtasks and/or to providing information about the simulation. A list of the tabs currently incorporated into **PC-Route**, along with a brief description of each tab function, is listed below. The listing reflects the sequence in which they occur within **PC-Route**:

Description of Tabs (Worksheets) contained in the PC-Route Spreadsheet

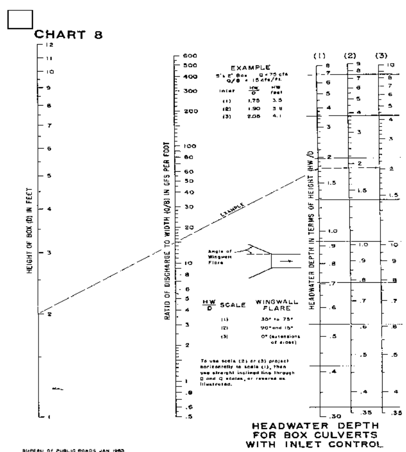
Worksheet Tab	Full Name	Explanation
Intro	Introduction	Application notes and usage warnings
Chron	Chronology	Sequential tabulation of improvements, bug fixes
In Out HG	Inflow and Outflow Hydrograph	Enter the inflow hydrograph, perform the routing simulation, and display the outflow hydrograph
Stage Vol	Stage / Volume Characteristics	Enter stage / volume characteristics for the facility geometry
Vol Outflow	Stage / Outflow Characteristics	Enter outflow element characteristics to develop stage / outflow relationship for the proposed outlet works
SO Work Curve	Storage / Outflow Working Curve	Develops the storage / outflow working curve from the input information
Summary	Single Sheet Output Summary	Summation of input and output information in report format
Out Elements	Outlet Element Graphic	Graphic to illustrate various characteristics for outflow elements
Conic Proj	Conic Projection Graphic	Graphic to document facility volume calculation by conic projection
Circ Crit Y	Circular Section Critical Depth	Develops the stage / discharge relationship for weir flow through an unsubmerged circular orifice
H, A, dV	Stage / area / ΔVolume	Design aid to calculate stage / area / volume data for facility shaped as truncated pyramid or cone, to be copied and pasted to the Stage Volume tab
Box	Box Culvert under Inlet Control	Develops the stage / discharge relationship for a box culvert outlet element flowing under inlet control

The **Intro** tab contains brief application guidelines and pertinent application notes and warnings. The District suggests review of the **Intro** tab prior to use of **PC-Route**, as this may save the user time and effort. The **Chron** tab tracks the various changes, updates, improvements, and bug fixes to **PC-Route,** and should also be reviewed prior to use.

PC-Route simulates passage of a single flood event through the facility. The single flood event is provided in the form of an inflow hydrograph, entered in the **<u>In Out HG</u>** tab. The inflow hydrograph must use a constant time increment, and may contain discharges for up to 200 time increments. Larger data sets may be accommodated by modifying the spreadsheet. **PC-Route** does not support use of a variable time increment for the inflow hydrograph. Multiple events, such as storms of different return frequencies, are simulated by multiple individual applications of **PC-Route**. Since each simulation contains a unique set of input data, documentation may be accomplished by saving a copy of **PC-Route** containing this data, with appropriate identifiers appended to the file name. Documentation may also be accomplished by printing out the individual tabs. These printouts may be included in the engineering design report for the facility.

Facility geometry is entered in the **<u>Stage Vol</u>** tab. Geometry may be constrained by site topography, property boundary, storm water storage characteristics, or other factors. The geometry is provided to the **<u>Stage Vol</u>** tab as a collection of data pairs. The data pairs are either stage / area, or stage / incremental (Δ) volume. For either data pair, the facility characteristics must begin at a stage of zero. Up to 26 data pairs may be used to describe the facility geometry. Additional data pairs may be accommodated by modifying the spreadsheet. If stage / area data pairs are provided, the **<u>Stage Vol</u>** tab calculates Δ volume at each stage by the conic projection method; this method is illustrated in the **<u>Conic Proj</u>** tab. Note that if the facility has the 3D shape of a truncated pyramid (rectangle in plan view) or cone (circular in plan view), or if such a shape is desired as a first approximation to the facility geometry, the stage / area or stage / Δ volume data may be developed within the **<u>H, A, dV</u>** tab given the length, width, side slope, and depth of a rectangular facility, or the bottom diameter, side slope, and depth of a circular facility.

Up to six outlet elements may be selected in the **<u>Vol Outflow</u>** tab for the facility outlet structure. These elements include a circular orifice, a triangular weir, 3 horizontal – crest weirs & a box culvert. The user specifies vertical placement and appropriate dimensions (span, rise, diameter, length, and/or side slope) to vary the outflow characteristics of the outlet. Illustration of these dimensions is shown on the **<u>Out Elements</u>** tab. When a circular orifice is selected, the **<u>Circ Crit Y</u>** tab develops the rating curve for the orifice as it operates under unsubmerged conditions, and passes the low flow rating curve to the **<u>Vol Outflow</u>** tab. Similarly, the **<u>Box</u>** tab develops the rating curve for a box culvert flowing under inlet control; this tab reproduces the relationship presented in the FHWA's HDS-5, Chart 8 for headwater depth for box culverts with inlet control. Selection of scale 1 to 3 (various wingwall flare) is accomplished by entering the appropriate coefficients in the blue – shaded areas on the tab for the desired scale. The **<u>Box</u>** tab passes the box culvert rating curve to the **<u>Vol Outflow</u>** tab when a box culvert is selected for inclusion into the outlet structure.



Routing of the inflow hydrograph through the facility is by the modified puls method. This method assumes a level pool and a constant time increment for the inflow hydrograph. The time increment must be less than the wave travel time through the facility. The modified puls method is based on a statement of conservation of mass, where over each time increment the outflow volume minus the inflow volume equals the change in storage within the facility. This is expressed in the following equation:

$$\tfrac{1}{2} * (I_1 + I_2) * \Delta t - \tfrac{1}{2} * (O_1 + O_2) * \Delta t = S_2 - S_1$$

Where: Subscript 1 signifies the first time step;
Subscript 2 signifies the second time step;
I = inflow, ft^3/s;
O = outflow, ft^3/s;
S = storm water storage in the facility, ft^3; and
Δt = inflow hydrograph constant time increment = $t_2 - t_1$, seconds.

Isolating the variables known at the first time step on the left side of the equation, and dividing by Δt produces the form which is used in **PC-Route**:

$$½ * (I_1 + I_2) + S_1/\Delta t - ½ * O_1 = S_2/\Delta t + ½*O_2$$

At the first time step, I_1, I_2, and Δt are known from the inflow hydrograph, and both S_1 and O_1 are zero (because the facility is empty). Substituting these values allows evaluation of the left side of the above equation for t_1. Given a graphical relationship between ($S/\Delta t + ½*O$) and O, the evaluated left side of the equation is equated to $S_2/\Delta t + ½*O_2$, and from the graphical relationship yields O_2. S_2 is calculated by back substitution of O_2 into $S_2/\Delta t + ½*O_2$. For the second time step, I_2, O_2, and S_2 evaluated for t_1 become I_1, O_1, and S_1 for the second iteration, while I_2 and Δt are known from the inflow hydrograph, and the process is repeated. By iteratively applying the equation in this fashion, the entire outflow hydrograph is obtained.

The graphical relationship between ($S/\Delta t + ½*O$) and O is developed within the **SO Work Curve** tab. In developing this relationship, the **SO Work Curve** tab interacts with the **Stage Vol** and **Vol Outflow** tabs. The process is like this: a stage is automatically selected, and from the **Stage Vol** tab, the corresponding storage is obtained. This same stage is provided to the **Vol Outflow** tab to determine the corresponding outflow. Having S, Δt and O, the data pair: (($S/\Delta t + ½*O$) , O) is calculated to provide one point on the graphical relationship. A second, higher, stage is then automatically selected, and the evaluation process is repeated. This iterative process proceeds until the selected stage exceeds the maximum design depth of the facility, and the resulting data pairs then compose the necessary graphical relationship.

3. Data Input for PC-Route

Within **PC-Route**, a color – coding scheme is applied to assist with data entry. This scheme is described on the **Intro** tab, and is repeated here:

Calc Notes:	• blue shaded cells are for input data
	• purple shaded cells are for optional input data
	• brown shaded cells are auto – populated from other worksheets
	• green shaded cells are intermediate calculation work areas
	• yellow shaded cells are for final calculated output

Accordingly, data input occurs only in the blue or purple shaded cells. All other cells are locked within Excel and are unavailable for input. Within the blue or purple shaded cells, data may be input by direct input from the keyboard or other input device, or by the cut and paste method. Cut and paste may be convenient for inputting the inflow hydrograph, since it usually involves entry of many numbers which are produced by some other software. All other information is typically provided by the keyboard.

Note that the purple shaded cells contain default equations which may be overwritten by input data if the user decides the default equations do not adequately describe the desired relationship. Within the spreadsheet these purple shaded cells occur within the **Vol Outflow** tab, where they are used to specify the rating curve for various outflow elements, and within the **Stage Vol** tab, where they are used to implement the conic projection method of volume calculation. Inputting data into these cells overwrites the default equations, and if the user later changes his/her mind and decides to return to the default equations, then the equations must be restored to these cells for proper operation. Restoration involves copying the equation(s) from an unmodified purple shaded cell within each column.

Many times, the entire blue – shaded input field is not needed to input all the available data. In this case, the unused blue – shaded area must remain unmodified, or must be cleared of all entries. Clearing is accomplished by highlighting the unused area, right – clicking, and selecting "Clear Contents".

Project, Job Identification: Identification of the project address and the investigator is accomplished within the **In Out HG** tab. A run date and program file name are also automatically entered in this area; these fields are shaded green, indicating that they cannot be directly

Desert Springs	Project Address
ADS	Data Sheet Preparer
Wednesday, December 14, 2011	Run Date
PC-ROUTE_01.xls	Program File Name

changed by the user. This identification information is automatically copied to other tabs, appearing in brown shaded cells.

Inflow Hydrograph: Input the return frequency for the simulation in years, the discharge values in ft^3/s, and the constant time increment in minutes, into the appropriate blue shaded cells on the **In Out HG** tab. The return frequency is only used to identify the inflow hydrograph and is not used in calculations. Up to 200 discharge values may be entered without modification to the spreadsheet. Zero (i.e., 0.0) discharge values preceding or succeeding the hydrograph are allowed. For illustration purposes, a portion of a 100 – year inflow hydrograph entered into the appropriate blue shaded area of the **In Out HG** tab, is shown here.

Input data:			
T	=	100	yr
Δt	=	0.4	min
index count		Inflow I, cfs	
	0	0.00	
	1	4.29	
	2	4.64	
	3	4.99	

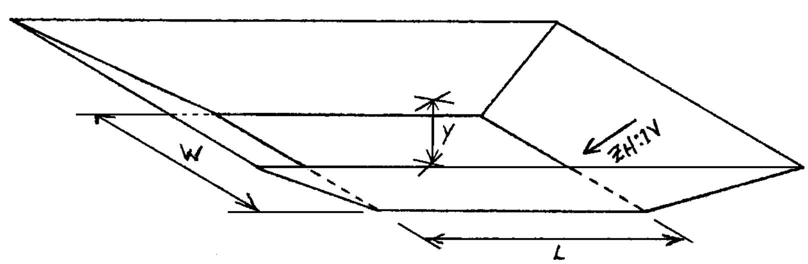
Stage / volume characteristics: This data is entered into the blue or purple shaded areas of the **Stage Vol** tab. Up to 26 data pairs may be entered without modification of the spreadsheet. Data pairs are either stage / area or stage / Δ volume. Regardless of the identity of the data pairs, the data set must begin at a stage and Δ volume of zero. Unused blue shaded cells beyond the data pairs are acceptable. For illustration purposes, a portion of the stage / volume characteristics entered into the appropriate blue or purple shaded areas of the **Stage Vol** tab, is shown here.

	stage H, ft	area A, ac	volume ΔV, af
Input data:	0.00	0.02966	0
	1.00	0.05245	0.04052
	2.00	0.07495	0.06337
	3.00	0.10339	0.08879

If the facility has the 3D shape of a truncated pyramid or cone, or if such a shape is desired as a first approximation to the facility geometry, the stage / area or stage / Δ volume data may be developed within the **H, A, dV** tab. To use this feature, the user must specify the length, width, side slope, and depth of a rectangular facility, or the bottom diameter, side slope, and depth of a circular facility. The stage / volume characteristics are computed by the tab, and may then be copied and pasted into the blue or purple shaded areas of the **Stage Vol** tab. A partial illustration of this tab used to develop the stage / volume data for a rectangular facility is shown below. In this illustration, the data in the yellow shaded area would be copied and pasted into the **Stage Vol** tab. The "paste special" option must be used: within the upper left corner of the blue shaded area in the **Stage Vol** tab, right click, select "paste special", then select "paste values".

Rectangular Detention / Retention Facility			
L =	200.00	Ft	length of bottom of detention facility
W =	200	Ft	width of bottom of detention facility
Z =	4	ft/ft	side slope (H:V) of detention facility
Y =	10	Ft	maximum depth of detention facility
ΔY =	0.4	Ft	depth increment
	25.00		number of lines of data in table

stage H, ft	Area A, ac	Volume ΔV, af
0.00	0.918	0.000
0.40	0.948	0.373
0.80	0.978	0.385
1.20	1.009	0.397
1.60	1.040	0.410
2.00	1.071	0.422
2.40	1.103	0.435
2.80	1.135	0.448



RECTANGULAR (truncated pyramid) FACILITY

Volume / Outflow characteristics: Outlet structure volume / outflow characteristics are developed within the **Vol Outflow** tab by selecting up to six outflow elements and specifying the geometry and hydraulic characteristics for each. Geometry and characteristics are entered into the blue shaded areas as shown:

ORIFICE OUTFLOW ELEMENT					
d_o (in) =	6	orifice diameter	area =	0.196	ft^2
C (dim) =	0.6	orifice discharge coefficient			
E_o (ft) =	1	stage at orifice center	inv =	9.00	in
				5.00	ft

TRIANGULAR WEIR OUTFLOW ELEMENT		
Z =	1.31	side slope (horiz:vert)
E_w =	5	stage at weir crest (ft)
C_1 =	1.34	discharge coefficient (dim)
Θ =	105	notch angle (deg)

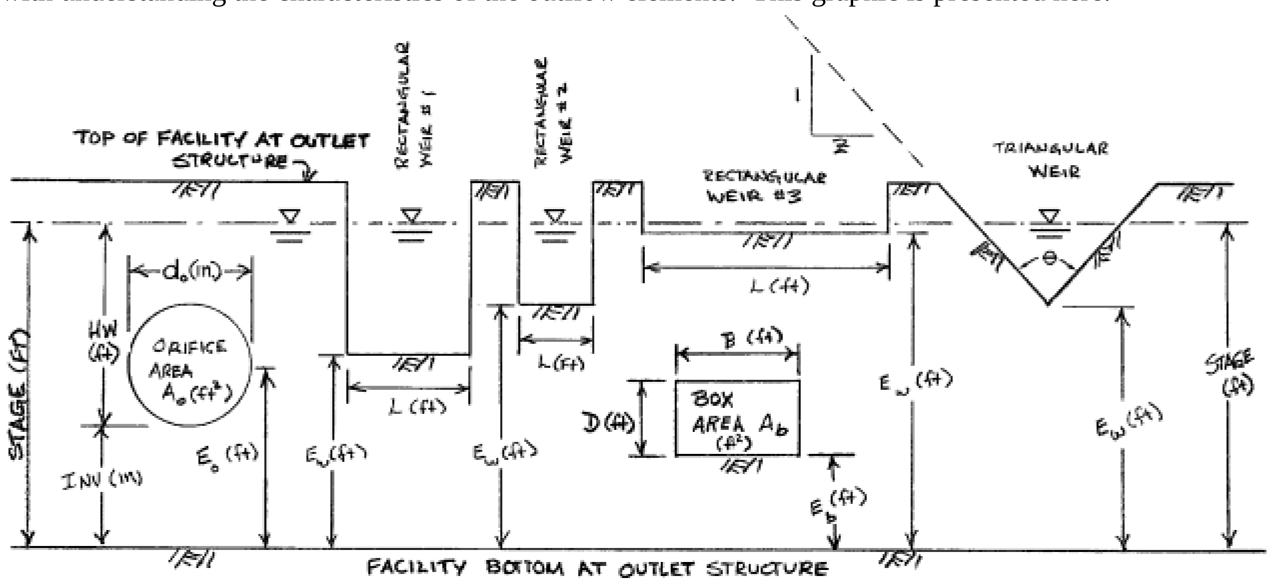
RECTANGULAR WEIR OUTFLOW ELEMENT(S)				
	rect 1	rect 2	rect 3	
L =	6	0	0	crest length (ft)
C =	3	3	3	discharge coefficient (dim)
E_w =	5	5	5	stage at weir crest (ft)

BOX CULVERT OUTFLOW ELEMENT		
D (ft) =	1.5	barrel rise
B (ft) =	0.5	barrel span
E_b (ft) =	0	barrel invert

If the user desires to incorporate an outflow element with a stage / discharge relationship which is not adequately described by the equations corresponding to one of the 6 optional elements, then the user must develop the discharges for each stage increment provided on the **Vol Outflow** tab, and then enter these discharges into the purple shaded area corresponding to one of the 6 optional elements. Entering the discharge value directly into the purple shaded cell will overwrite the optional discharge equation within the cell.

	Basin		Weir Element(s)						
	Stage H, ft	Orifice Q, cfs	Triang 1 Q, cfs	Rect 1 Q, cfs	Rect 2 Q, cfs	Rect 3 Q, cfs	RCP Box Q, cfs	Outflow O, cfs	Σ vol S, af
Interm Calcs:									
	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00000
	0.15	0.00	0.00	0.00	0.00	0.00	0.092	0.09	0.00608
	0.18	0.00	0.00	0.00	0.00	0.00	0.117	0.12	0.00729

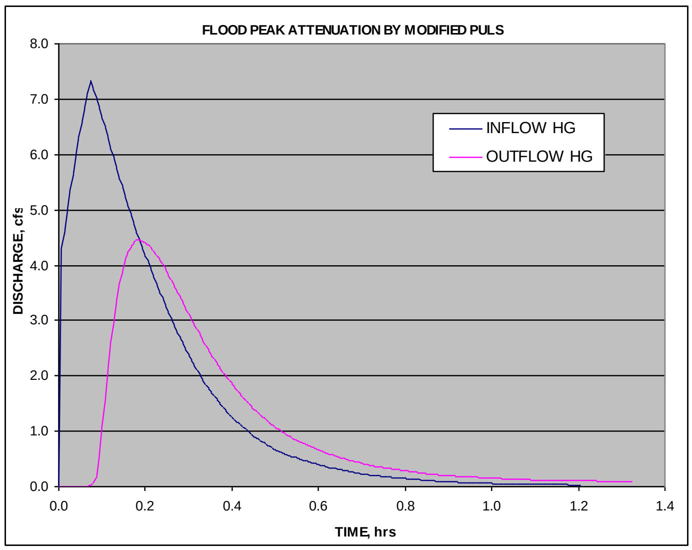
Once the outflow elements are selected, and/or the stage / discharge relationship(s) are developed outside of **PC-Route** and entered in the purple shaded areas, the tab divides the maximum design facility stage into 100 equal stage increments, calculates outflow for each selected outflow element at each stage increment, then totals the outflow from all selected outflow elements at each stage increment. The tab reads the maximum design facility stage from the **Stage Vol** tab. The user may disable various outflow elements by either placing the outflow element above the maximum design facility stage, or by specifying zero area (orifice or box), or zero crest length (horizontal weir). The graphic in the **Out Elements** tab may assist with understanding the characteristics of the outflow elements. This graphic is presented here:



One additional set of calculations is accomplished within the **Vol Outflow** tab, in order to facilitate development of the Storage / Outflow Working Curve. These calculations determine the facility storage associated with each stage increment used in the **Vol Outflow** tab. Storage at each stage is calculated by referencing the stage versus storage results contained within the **Stage Vol** tab. During this referencing, if the stage increment from the **Vol Outflow** tab falls between stage values presented in the **Stage Vol** tab, the facility storage at the stage increment is determined by linear interpolation.

Storage / Outflow Working Curve: The Storage / Outflow Working Curve is developed within the **SO Work Curve** tab. No input data is required on this tab; calculations are performed automatically. With completion of the storage / outflow working curve, the routing simulation will automatically proceed. One particular note is important: Through the sequence of the routing calculations, the value of $S_2/\Delta t + ½*O_2$ (function value) is periodically passed to the storage / outflow working curve to determine the corresponding value of O_2. If the function value passed to the tab does not exactly match a function value for one of the calculated data pairs which compose the working curve and which were calculated within the **SO Work Curve** tab, then linear interpolation is used to derive the corresponding value of O_2.

4. **Viewing Results from PC-Route:**



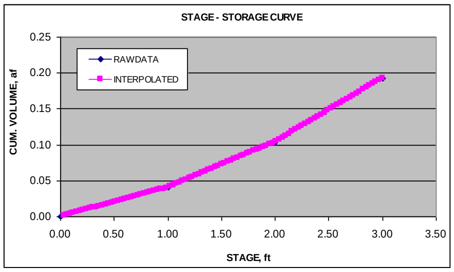
Results of the storm water hydrograph routing simulation are in the form of an outflow hydrograph from the facility, and a few associated characteristics of the hydrograph and of the facility operation. The outflow hydrograph is plotted with the inflow hydrograph for comparison, on both the **In Out HG** tab and the **Summary** tab. These same tabs also present two lines of results, consisting of maximum inflow and outflow in ft^3/s, the volume of storm water runoff contained in the inflow hydrograph (ft^3 & ac–ft), the stage (feet) in the facility at maximum outflow, and the time of maximum outflow. Both tabs also present the maximum design facility stage (copied from the **Stage Vol** tab) to allow comparison with the calculated facility stage at maximum outflow. The user is cautioned that if this comparison shows the calculated stage at maximum outflow is equal or greater than the maximum design facility stage, then the stage / volume data presented on the **Stage Vol** tab must be extended to a higher stage in order to insure accurate simulation results.

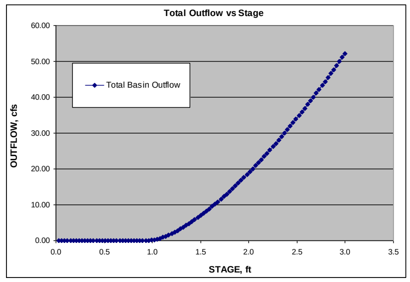
RESULTS:	Max Inflow =	7.3	cfs	inflow vol =	6665	ft^3	Or	0.153	Af
	Max Outflow =	4.5	cfs	at H =	1.36	ft	& t =	11.2	Min

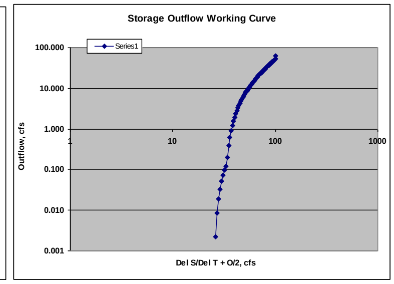
Max Stage = 3.00 ft	**NOTE: IF H > MAX STAGE, EXTEND STAGE / VOL DATA TO A HIGHER STAGE**

Partial results are also presented on the **Vol Outflow** tab, to facilitate design of the outlet structure. In this way, from the **Vol Outflow** tab the user may vary the characteristics of individual outflow elements and directly view the resulting change in the outflow hydrograph characteristics (peak discharge, maximum stage, and time of maximum outflow). Note that the summary information throughout the spreadsheet is presented in yellow shaded cells, indicating final calculated output in accordance with the color scheme presented in the **Intro** tab.

Graphs are provided within each separate tab, showing the results of each subtask of the simulation. These graphs are useful in verifying proper data input, since an outlier in the input data will generally distort the graph. The user is advised to inspect these graphs during the data input phase to insure accurate and realistic data input, and after the routing simulation to insure proper operation of **PC-Route**. These graphs include the stage / volume relationship, the stage / outflow relationship, and the storage / outflow working curve:







5. **Design Example**

A storm water detention / retention facility (facility) is to be constructed within a critical basin as part of a commercial development plan. Due to being located within a critical basin, a 10% reduction in peak discharge is required for the 2 – year, 10 – year, and 100 – year peak pre project discharges. For this particular development plan, the watershed in which the facility is to be constructed has the following pre and post project hydrologic characteristics:

Storm Frequency	Pre Project Peak Discharge, ft^3/s	Pre Project Peak with 10% Reduction, ft^3/s	Post Project Peak Discharge, ft^3/s
2 – Year	4.5	4.1	8.2
10 – Year	12.0	10.8	22.0
100 – Year	30.0	27.0	55.0

The facility is to be constructed with approximately 55,000 ft^3 of storage, and will have a level bottom with a bottom area of 8600 ft^2. The facility is to provide 6 inches of storm water harvesting for landscape irrigation. The outlet structure is a V – notch weir, with the bottom of the notch set 6 inches above the bottom of the facility, the depth of the notch is 2 feet, and the notch opening at the top is 40 inches. These dimensions will produce a V – notch with an interior angle of approximately 80 degrees. Discharge coefficient for the V – notch weir is set to 2.50.

The inflow hydrograph to the facility is developed using the PC Hydro software. Input to PC Hydro includes the watershed characteristics under post project conditions, which are: watershed area of 8.7 acres of which 20% is impervious and the remaining area is covered with desert brush at a 30% cover density, the desert brush is supported by SCS Hydrologic Soil Group (HSG) Type B soils. Due to construction of hydraulic structures to concentrate and direct surface runoff, a basin factor of 0.022 was selected. The watercourse length is 1360 ft at a mean slope of 0.015 ft/ft. The 100 – year post project hydrograph from PC Hydro, printed with a time increment of 1 minute in order to capture the peak discharge, is listed in Table I below. Design of the earthwork for the storm water detention / retention facility produced the stage / volume characteristics listed in Table II below.

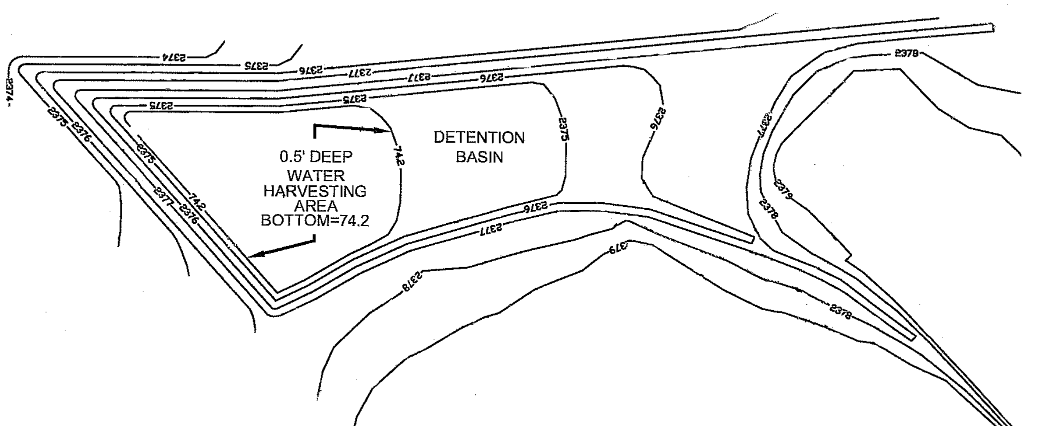
In order to route the 100 – year post project hydrograph through the facility with the specified stage / storage characteristics and outlet structure, the project information was entered into the appropriate tabs of **PC-Rout**e. The frequency, time increment, and inflow hydrograph were entered on the **In Out HG** tab along with the project address and identification of the investigator; the stage / storage characteristics were entered on the **Stage Vol** tab; and the V – notch weir characteristics were entered on the **Vol Outflow** tab. The crest of the outflow V – notch weir was set 6 inches above the bottom of the facility in order to harvest the first 6 inches of storm water storage for irrigation use within the development. The result of this routing effort for the 100 – year event was a peak outflow of 10.4 ft^3/s, which is below the maximum allowable of 27.0 ft^3/s (= 0.90 * 30 ft^3/s). **PC-Route** shows the peak outflow occurred at a stage of 2.4 feet, which is below the maximum design stage of 2.8 feet and which puts a maximum head of 1.9 feet on the 2 foot high outflow structure (V – notch weir). Note that the complete design effort will involve similarly routing the 2 – year and the 10 – year post project hydrographs through the same storm water facility in order to demonstrate that the outflow discharges for these frequency storms, as well as for the 100 – year storm, are less than 90 % of the corresponding pre project peak discharges. For illustration purposes, the individual tabs from **PC-Route**, containing the above input information, are included here.

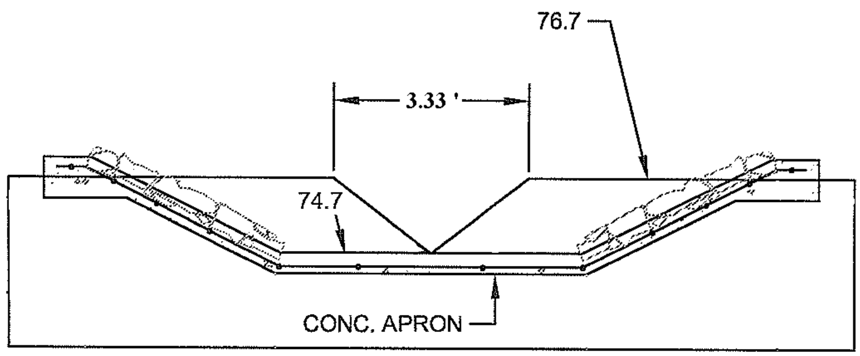
Table I
100 – year Post Project
INFLOW HYDROGRAPH TO STORM WATER DETENTION FACILITY

Time, min	Q, ft^3/s		Time, min	Q, ft^3/s		Time, min	Q, ft^3/s
0	0.00		33	9.53		66	0.54
1	1.01		34	8.66		67	0.49
2	2.98		35	7.79		68	0.44
3	5.61		36	7.04		69	0.42
4	8.56		37	6.35		70	0.41
5	11.89		38	5.67		71	0.39
6	15.70		39	5.16		72	0.38
7	19.88		40	4.68		73	0.36
8	24.13		41	4.23		74	0.34
9	29.05		42	3.94		75	0.33
10	34.82		43	3.64		76	0.31
11	41.31		44	3.35		77	0.29
12	47.34		45	3.06		78	0.28
13	52.26		46	2.77		79	0.26
14	55.00		47	2.55		80	0.25
15	50.68		48	2.36		81	0.23
16	47.25		49	2.16		82	0.21
17	43.86		50	1.97		83	0.20
18	40.57		51	1.78		84	0.18
19	37.42		52	1.62		85	0.17
20	34.42		53	1.52		86	0.15
21	31.79		54	1.42		87	0.13
22	29.36		55	1.31		88	0.12
23	26.82		56	1.21		89	0.10
24	24.45		57	1.11		90	0.08
25	22.23		58	1.04		91	0.07
26	20.14		59	0.97		92	0.05
27	18.16		60	0.90		93	0.04
28	16.44		61	0.83		94	0.02
29	14.78		62	0.75		95	0.00
30	13.15		63	0.69		96	
31	11.90		64	0.64		97	
32	10.65		65	0.59		98	

Table II
STAGE – STORAGE CHARACTERISTICS FOR THE STORM WATER FACILITY

Stage	Area		stage	Area
H, ft	A, ac		H, ft	A, ac
0.00	0.19931		1.30	0.42119
0.10	0.21885		1.40	0.43434
0.20	0.23836		1.50	0.44747
0.30	0.25790		1.60	0.46061
0.40	0.27741		1.70	0.47374
0.50	0.29695		1.80	0.48687
0.60	0.31648		1.90	0.50737
0.70	0.33600		2.00	0.52787
0.80	0.35553		2.10	0.54837
0.90	0.36866		2.20	0.56887
1.00	0.38180		2.30	0.58937
1.10	0.39493		2.40	0.60989
1.20	0.40806		2.80	0.69190





DETENTION BASIN OUTLET WEIR

PIMA COUNTY REGIONAL FLOOD CONTROL DISTRICT

ROUTING OF A FLOOD HYDROGRAPH THROUGH A STORMWATER DETENTION / RETENTION FACILITY

Worksheet to Input the Inflow Hydrograph, & to Automatically Perform the Routing Calculations using the Stage-Volume data, Volume-Outflow data, & SO Working Curve

Rev. 12/11

Example for Detention / Retention Manual	**Project Address**
ADS	**Data Sheet Preparer**
Wednesday, June 27, 2012	**Run Date**
PC-ROUTE_01.xls	**Program File Name**

GOVERNING EQUATIONS: *Ref: Handbook of Applied Hydrology (Ven Te Chow, Editor 1964)*

Conservation of mass: $0.5 * (I_1 + I_2) * \Delta t - 0.5 * (O_1 + O_2) * \Delta t = S_2 - S_1$ Eq 25-II-4

Isolate knowns, divide by Δt: $0.5 * (I_1 + I_2) + S_1 / \Delta t - 0.5 * O_1 = S_2 / \Delta t + 0.5 * O_2$ Eq 25-II-5

Note: Input Δt & inflow hydrograph into blue shaded area; outflow hydrograph (yellow) is calculated from selected outflow configuration (vol-outflow tab) and facility geometry (Stage-Vol tab). **To add rows to this worksheet**, add them in roughly the center of the range, then unhide columns J through S & copy hidden equations into the new rows. Zero discharge beyond the end of the hydrograph will not affect the simulation.

VARIABLES:

Δt	sec	time interval over which inflow hydrograph is linear, and which is less than travel time through facility
I_1, I_2	cfs	inflow rate into facility at start and end of time interval from inflow flood hydrograph
O_1, O_2	cfs	facility outflow rate at start & end of time interval from outlet works characteristics (function of stage)
S_1, S_2	ft^3	stormwater in storage in the facility at start and end of time interval

RESULTS:

Max Inflow =	55.0	cfs	inflow vol =	57150	ft^3	or	1.312	af	Max Design Stage =	
Max Outflow =	10.4	cfs	at Stage (H) =	2.40	ft	& t =	32	min	2.80 ft	

NOTE: IF H > MAX DESIGN STAGE, EXTEND STAGE-VOL DATA TO A HIGHER STAGE

Input data:

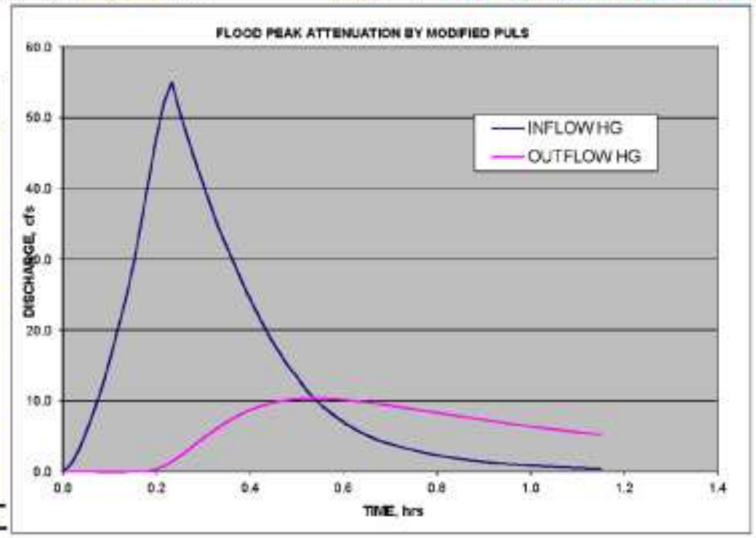
T = 100 yr inflow hydrograph return period

Δt = 1 min 0.0167 hr inflow hydrograph

index count	Inflow I, cfs	time t, hr	S/Δt+O/2 cfs	outflow O, cfs	Stage H, ft
0	0.00	0.0000	0.000	0.00	0.00
1	1.01	0.0167	0.505	0.00	0.00
2	2.98	0.0333	2.500	0.00	0.02
3	5.61	0.0500	6.795	0.00	0.04
4	8.56	0.0667	13.880	0.00	0.09
5	11.89	0.0833	24.105	0.00	0.15
6	15.70	0.1000	37.900	0.00	0.23
7	19.88	0.1167	55.690	0.00	0.33
8	24.13	0.1333	77.695	0.00	0.44
9	29.05	0.1500	104.285	0.00	0.56
10	34.82	0.1667	136.218	0.04	0.70
11	41.31	0.1833	174.245	0.15	0.85
12	47.34	0.2000	218.418	0.40	1.01
13	52.26	0.2167	267.822	0.81	1.18
14	55.00	0.2333	320.639	1.43	1.36
15	50.68	0.2500	372.050	2.19	1.52
16	47.25	0.2667	418.823	3.02	1.66
17	43.86	0.2833	461.359	3.88	1.78
18	40.57	0.3000	499.696	4.73	1.88
68	0.44	1.1333	526.311	5.36	1.96
69	0.42	1.1500	521.384	5.24	1.94

Intermediate Calcs:

Results:



PIMA COUNTY REGIONAL FLOOD CONTROL DISTRICT

ROUTING OF A FLOOD HYDROGRAPH THROUGH A STORMWATER DETENTION / RETENTION FACILITY

Worksheet to Input the Stage - Volume Relationship for the Stormwater Detention / Retention Facility

Example for Detention / Retention Manual	Project Address
ADS	Data Sheet Preparer
Wednesday, June 27, 2012	Run Date
PC-ROUTE_01.xls	Program File Name

Rev.12/11

GOVERNING EQUATIONS: *Ref: HEC-1 Flood Hydrograph Package User's Manual (USACOE September 1990)*

Conic method for Reservoir Volumes: $\Delta V_{1-2} = 0.33 * h * (A_1 + A_2 + (A_1 * A_2)^{0.5})$ (see "**Conic Proj**" tab)

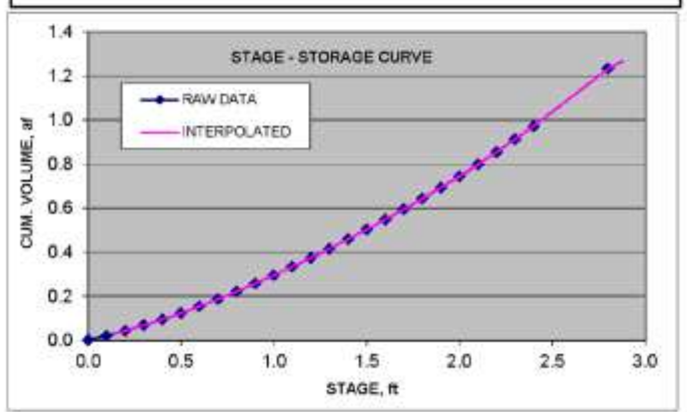
VARIABLES:

ΔV_{1-2}	af	incremental facility storage volume between stages H_1 and H_2
h	ft	elevation difference between A_1 and A_2
A1, A2	ac	facility surface area at stages H_1 and H_2

2.80 = max design stage (ft)

	stage H, ft	area A, ac	volume ΔV, af	for information only: area A, ft²	volume ΔV, ft³	Σ ΔV S, ft³	Σ ΔV S, af
Input data:	0.00	0.19931	0	8682	0	0	0.000
	0.10	0.21885	0.021	9533	910	910	0.021
	0.20	0.23836	0.023	10383	996	1906	0.044
	0.30	0.25790	0.025	11234	1061	2986	0.069
	0.40	0.27741	0.027	12084	1166	4152	0.095
	0.50	0.29695	0.029	12935	1251	5403	0.124
	0.60	0.31648	0.031	13786	1336	6739	0.155
	0.70	0.33600	0.033	14636	1421	8160	0.187
	0.80	0.35553	0.035	15487	1506	9666	0.222
	0.90	0.36866	0.036	16059	1577	11243	0.258
	1.00	0.38180	0.038	16631	1634	12877	0.296
	1.10	0.39493	0.039	17203	1692	14569	0.334
	1.20	0.40806	0.040	17775	1749	16318	0.375
	1.30	0.42119	0.041	18347	1806	18124	0.416
	1.40	0.43434	0.043	18920	1863	19987	0.459
	1.50	0.44747	0.044	19492	1921	21907	0.503
	1.60	0.46061	0.045	20064	1978	23885	0.548
	1.70	0.47374	0.047	20636	2035	25920	0.595
	1.80	0.48687	0.048	21208	2092	28012	0.643
	1.90	0.50737	0.050	22101	2165	30178	0.693
	2.00	0.52787	0.052	22994	2255	32432	0.745
	2.10	0.54837	0.054	23887	2344	34776	0.798
	2.20	0.56887	0.056	24780	2433	37209	0.854
	2.30	0.58937	0.058	25673	2523	39732	0.912
	2.40	0.60989	0.060	26567	2612	42344	0.972
	2.80	0.69190	0.260	30139	11334	53677	1.232
Intermediate Calcs:							

Note: Develop stage-storage curve on this worksheet by either entering planimetered basin areas (in acres) at various stages (blue shaded area) or by entering facility stages and corresponding incremental volumes (acre-feet, purple shaded column). Graph of the stage-storage curve shown to verify proper interpolation (purple points) of facility volume by **Vol Outflow** tab. **You may insert rows into the middle of this table** to accomodate the size of your data set; empty rows below the extent of your data will not cause a problem. However, if you insert rows, you must unhide the hidden columns (columns K through N) and copy the hidden equations into the new rows. **Stage - Volume data must begin at stage = 0 ft with a volume of 0 af.**



PIMA COUNTY REGIONAL FLOOD CONTROL DISTRICT

ROUTING OF A FLOOD HYDROGRAPH THROUGH A STORMWATER DETENTION / RETENTION FACILITY

Worksheet to Develop the Stage - Discharge Characteristics of the Outflow Structure for the Stormwater Detention / Retention Facility

Rev. 12/11

Example for Detention / Retention Manual	Project Address
ADS	Data Sheet Preparer
Wednesday, June 27, 2012	Run Date
PC-ROUTE_01.xls	Program File Name

Note: Populate characteristics of selected outflow elements corresponding to facility outlet configuration (blue shaded areas), or overwrite purple shaded areas with outflows calculated outside this worksheet, as a function of the given facility stages. Storage (last column) at each stage is interpolated from stage-volume relationship (see "**Stage Vol**" tab). **Do not add rows** to this worksheet; it automatically divides maximum facility design stage into 100 increments to develop the volume-outflow curve.

GOVERNING EQUATIONS:

Orifice equation: $Q_o = C * A * (2 * g * H)^{0.5}$ and see weir flow equation on "**Circ Crit Y**" tab

Rectangular Weir Equation: $Q_w = C * L * H^{1.5}$

Triangular Weir Equation: $Q_w = C_t * Tan(\theta/2) * H^{2.5}$

Box Culvert Equation: See Box Culvert equations for Inlet Control on "**Box**" tab

ORIFICE OUTFLOW ELEMENT					
d_o (in) =	6	diameter	area (ft²) =	0.196
C (dim) =	0.6	disch coefficient	inv (in) =	57.00
E_o (ft) =	5	stage at center	inv (ft) =	4.750

TRIANGULAR WEIR OUTFLOW ELEMENT		
Z =	0.839	side slope
E_w (ft) =	0.5	stage at crest
C_t =	2.5	disch coefficient
Θ (deg) =	80.0	notch angle

RECTANGULAR WEIR OUTFLOW ELEMENT(S)	rect 1	rect 2	rect 3	
L (ft) =	1	0	0	crest length
C =	3	3	3	disch coefficient
E_w (ft) =	5	5	5	stage at crest

BOX CULVERT OUTFLOW ELEMENT		
D (ft) =	1.5	barrel rise
B (ft) =	0.5	barrel span
E_b (ft) =	5	barrel invert

Basin Stage H, ft	Orifice Q, cfs	Weir Element(s) Triang 1 Q, cfs	Rect 1 Q, cfs	Rect 2 Q, cfs	Rect 3 Q, cfs	RCP Box Q, cfs	Outflow O, cfs	Σ vol S, af
Intermediate Calcs:								
0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.00000
0.14	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.03004
0.17	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.03690
0.20	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.04375
0.22	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.04872
0.25	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.05616
0.28	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.06360
0.31	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.07124
0.34	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.07926
0.36	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.08462
0.39	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.09264
0.42	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.10106
0.45	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.10968
0.48	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.11829
0.50	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.12403
0.53	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.13323
0.56	0.00	0.00	0.00	0.00	0.00	0.000	0.00	0.14243
0.59	0.00	0.01	0.00	0.00	0.00	0.000	0.01	0.15163
0.62	0.00	0.01	0.00	0.00	0.00	0.000	0.01	0.16122
0.64	0.00	0.02	0.00	0.00	0.00	0.000	0.02	0.16775
0.67	0.00	0.02	0.00	0.00	0.00	0.000	0.02	0.17753
0.70	0.00	0.04	0.00	0.00	0.00	0.000	0.04	0.18732
0.73	0.00	0.05	0.00	0.00	0.00	0.000	0.05	0.19769
2.88	0.00	18.33	0.00	0.00	0.00	0.000	18.33	1.26747
2.80	0.00	16.83	0.00	0.00	0.00	0.000	16.83	1.23226
2.86	0.00	17.87	0.00	0.00	0.00	0.000	17.87	1.25691

SIMULATION RESULTS PRESENTED HERE TO FACILITATE OUTLET DESIGN							
Max Outflow =	10.4	cfs	at Stage (H) =	2.40	ft	δt =	32	min