The Extention Basin as a Storm Water Control Device

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Abstract

This paper proposes an integrated approach to storm water management and storm water treatment. Today's requirements for capturing and treating storm water can be met with a new device that also controls peak flows over a wide range of storms and uses a net storage volume that is substantially lower than the storage computed by traditional reservoir routing methods.

The extention basin debuts here as the most efficient method of reducing peak storm water flows—being far more effective than the retention or detention basins in common use today.

Background—Storm Water Management

The most effective, and possibly the only device for simply reducing or controlling storm water peak flow, is the storage basin—commonly known as a retention or detention basin. The term detention basin has come to be distinguished from a retention basin in that the latter is a storage device that has a normal pool of water such as a lake; pond or reservoir, while the detention basin is considered dedicated to its task and is normally empty. Both of these operate by the natural accumulation of storm water when a restriction, such as a weir or orifice, is placed on the flow.

These storage basins are typically used to mitigate storm water increases due to land development and are very effective when designed properly. For example, in a small watershed of 5 acres, for a shopping center that converts an existing wooded site to a land use consisting of pavement, the peak storm water flows can rise from 10 cfs to 20 cfs rather easily. In larger watersheds, proportional increases such as these could cause serious flooding and environmental damage.

The key criterion in storm water management is the limitation of after-development peak flows to rates equal to or less than the peak flows prior to development. In the example above, the developer of the shopping center would need to provide a storage basin to limit the after-development peak flows to 10 cfs. The developer may then need to provide substantial water quality treatment storage. Of course, the storage basin would occupy a significant portion of the site, typically ranging from five (5) to fifteen (15) per cent or more of the development land area.

Many state and local municipalities normally require either control of storm water through written codes or insist on peak flow controls during the approval process. Whether or not storm water control is required, it is usually prudent to control storm water flows that are destined for off-site areas, merely to reduce the liability for damages in case of downstream flooding.

Background—Storm Water Treatment

The treatment of storm water to improve water quality has gained considerable interest. Federal and state regulations now require storm water treatment for large sites and new Federal NPDES rules require treatment from small sites. Further, some local municipal codes or environmental concerns mandate some form of storm water treatment for all sites.

A key criterion of storm water treatment is the capture of the first flush or water quality volume of about 1/2 inch of runoff from newly disturbed areas within the watershed. The great majority of pollutants from runoff are contained in the first-flush. To treat first-flush, the flows must be conveyed to specially designed water quality treatment basins where a variety of treatment processes take place, culminating with filtration, infiltration to the soil and/or evaporation. The water quality basins are designed particularly to capture only the first-flush of runoff, and to avoid the later segments of the runoff that would mix with and wash out the captured flow.

Our firm developed a simple design for a first-flush control device in 1990 that we have been using since on various engineering projects. Essentially, the control works on a hydraulic balancing principle – diverting the low flows to a water quality basin and then permitting direct conveyance back to the drainage system or local stream when the water quality basin is full. The water quality basin is designed to store water for just a few days since an empty basin is necessary at the time of rainfall to fulfill the goal of water quality treatment.

Storm Water Storage Basin Theory

The method of computation used to design storm water storage systems is the straightforward and familiar application of conservation of mass principles—the volume flowing out is equal to the volume flowing into a system. This is known as the reservoir routing method, and a wide range of information is available on the subject in engineering and hydrology texts. A brief summation of the method is given here, as follows:

It is assumed for the numerical solution, that we are given the flow "Q" at every time interval "t", being the series, Qin(t).

Given: Vol (out) = Vol (in): Q(out) is flow from storage basin

If a volume is allowed to accumulate (S), the modified mass equation accounts for this as follows:

Vol (out) = Vol (in) – S

In a time interval t:	Vol(out)/Δt = Vol(in)/Δt – ΔS/Δt	
Since:	Vol(out)/Δt = Qout(t)	
And, since:	Vol(in)/Δt = Qin(t) and	ΔS = S(t)
Substituting	Qout(t) = Qin(t) – ΔS/Δt	

Rearranging: S(t) = (Qin(t) - Qout(t)) x Δt (Eq. 1)

The Extention Basin uses a modified storage equation which adds two new terms which account for flow bypassing the storage basin and flow to an infiltration water quality basin, as follows:

EBS Equation S(t) = (Qin(t) - Qout(t)-Qbypass(t)-Qwq(t)) x Δt

The outflow of a storage basin can be modeled by a non-linear hydraulic function, "g" relating head, or height (stage) "H" in the basin, and various physical characteristics of the control device; e.g., length of a weir or diameter of a pipe, referred to as the set "n", and generally a constant "C".

For example: Qout = C x g(n, H) (Eq. 2)

If the outflow of a storm water storage basin is restricted by a weir, the outflow function is as follows:

Q=C x L x H^3/2 or Qout(t)=C x L x H(t)^3/2

Where: C is a factor (3.337)
L is the weir length (ft)

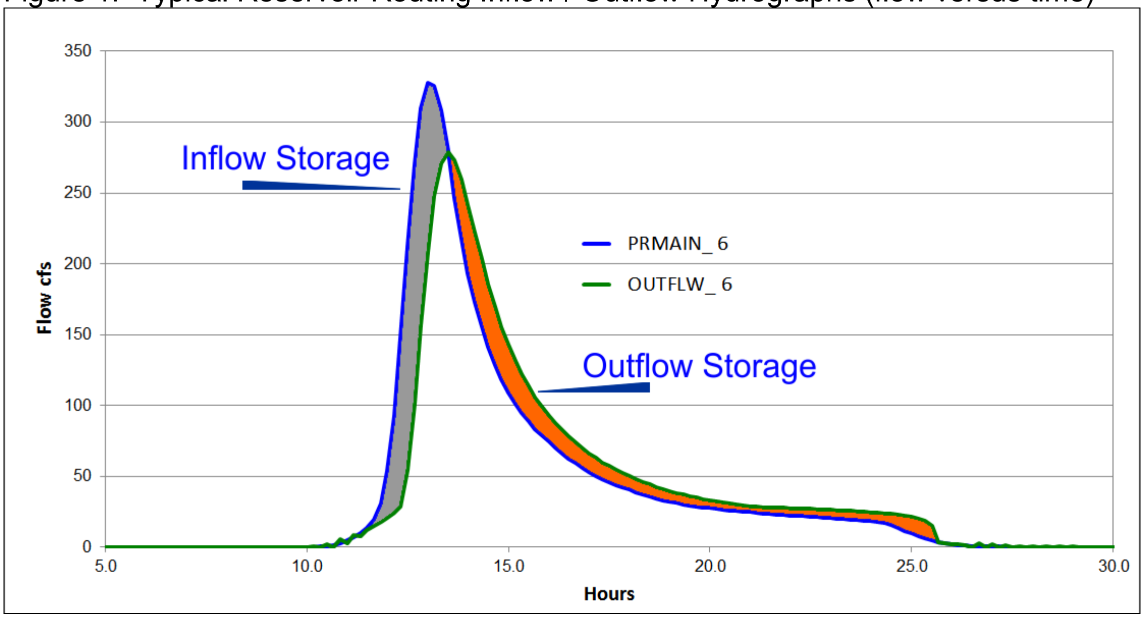
H is the flood stage in the basin in feet and H(t) is the height at any time

Further, there is a natural geometric relationship, or function "f" between height "H" and the volume "S" in the storage basin. This is often a tabular relationship between contour elevation and surface area that can readily be interpolated for storage volume at any height.

For example: H =f(S) or H(t)=f(S(t)) (Eq. 3)

Equations 1, 2 and 3, above fully define the mathematics of the storage process that occurs in a detention or retention basin. The equations are easily solved by iterative techniques. The mathematical method is generally referred to by the generic term, reservoir routing, and it describes a relationship between inflow and outflow that can be seen graphically below:

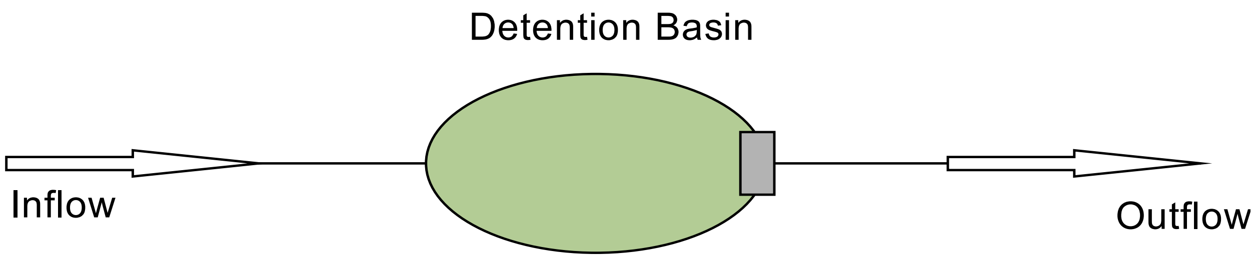
Figure 1: Typical Reservoir Routing Inflow / Outflow Hydrographs (flow versus time)



It is important to note that the area between the inflow and outflow hydrograph is the exact equivalent of the storage volume reached in the storm water basin. Further, in the descending phase of the inflow, the area representing the outflow volume leaving the storage system is the same as the inflow volume, unless some volume is captured within the system.

The hydrographs in Figure 1 represent the flow in and out of a typical storage basin whose flow paths are represented by the figure below:

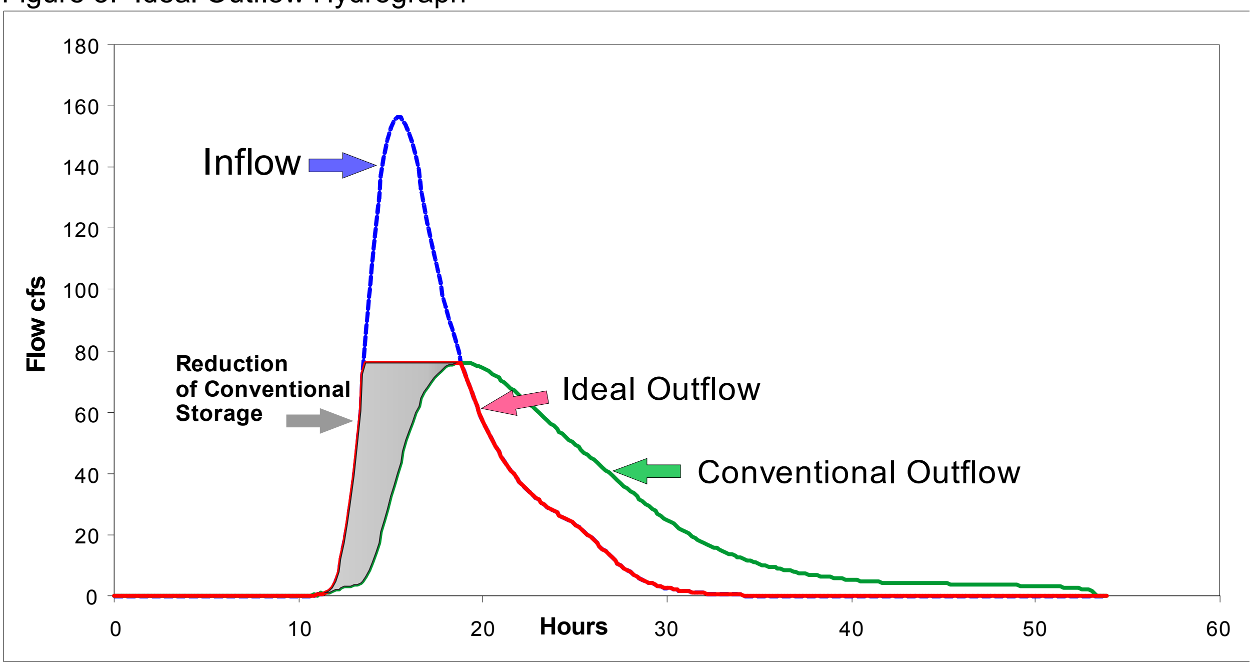
Figure 2: Typical Storage Basin System Flow Path



The Simple Extention Basin

To absolutely minimize the amount of storage volume needed, one must allow the outflow hydrograph to closely track the rise in the inflow hydrograph until a pre-determined flow is reached. In theory, the most efficient storage basin—one with the least storage for the same flow reduction, is one whose outflow follows this non-continuous route, as shown below:

Figure 3: Ideal Outflow Hydrograph



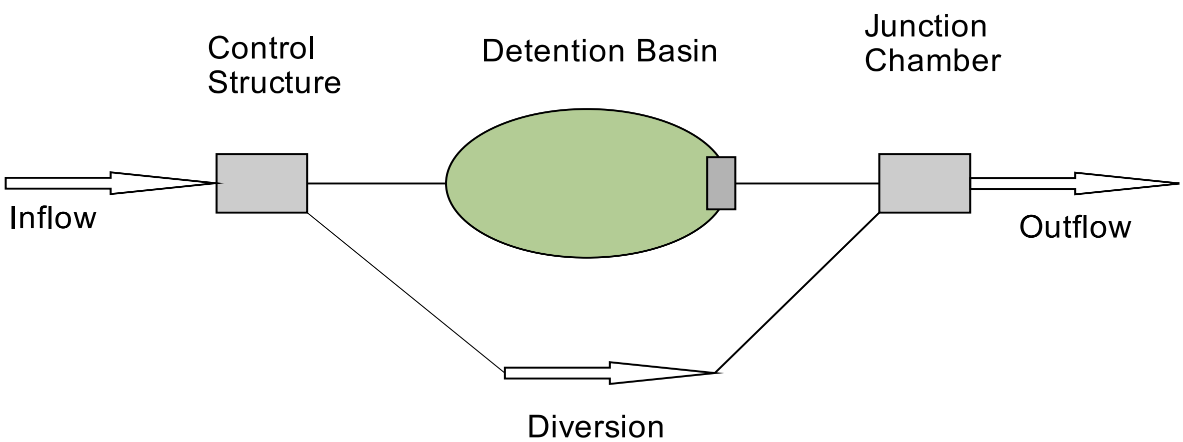
Such an outflow function is difficult to replicate using standard reservoir routing, though it can be provided by using mechanical intervention. For example, to restrict outflows to, say 75 cfs, an operator can be stationed at a valve in the system. The operator would know when to open the valve and divert flows away or towards the design point.

This mechanical system is not acceptable in practice for a variety of reasons, least of which is the reliance on mechanical means in perpetuity as well as the monitoring of rainfall and runoff rates. Clearly, a fully non-mechanical method of performing the same task is our goal.

The extention basin provides such an automatic function. It operates hydraulically and non-mechanically, by allowing the storm flow to bypass the storage basin during the ascending part of the storm then diverts flow into the storage basin only during the period of peak inflow. The extention basin provides flow reductions through external control structures and external piping, and extends the functionality of the storage basin by adding water quality treatment, hence the given name.

A flow schematic of a simple extention basin operation follows:

Figure 4: Simple Extention Basin System Flow Path



Operation of the Extention Basin

An extention basin will control peak flows over a range of storm frequencies. The following is a narrative of the operation and components of the extention basin.

1. Inflows are directed to the external control structure that is comprised of a low-level pipe outlet and a high level, diverting weir. The low flows bypass the storage basin in the bypass piping and are conveyed to a junction point.

2. At a calculated high-level flow, the diverting weir develops enough head to discharge to the storage basin. Generally, the diverting weir is long to allow a rapid flooding into the storage basin.

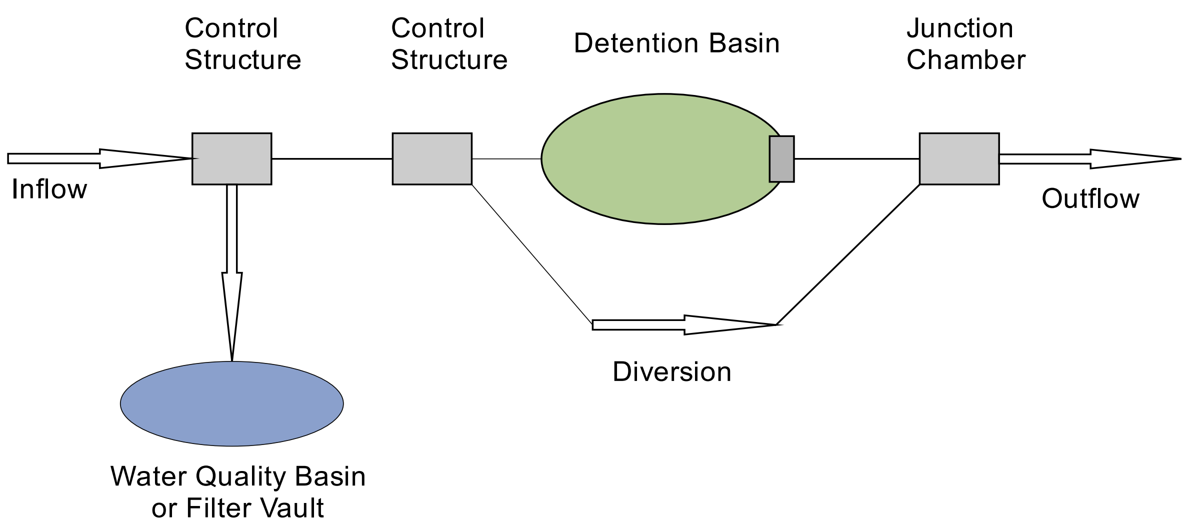
3. At mid-level to high-level flows, the storage basin takes the bulk of the main flow with some limited bypass continuing in the low flow piping.

4. The outflow of the storage basin, as controlled by the internal control structure, a weir, pipe or combinations, joins with the low flow bypass to produce a combined total outflow at the design point.

Operation of the Extention Basin with Storm Water Treatment

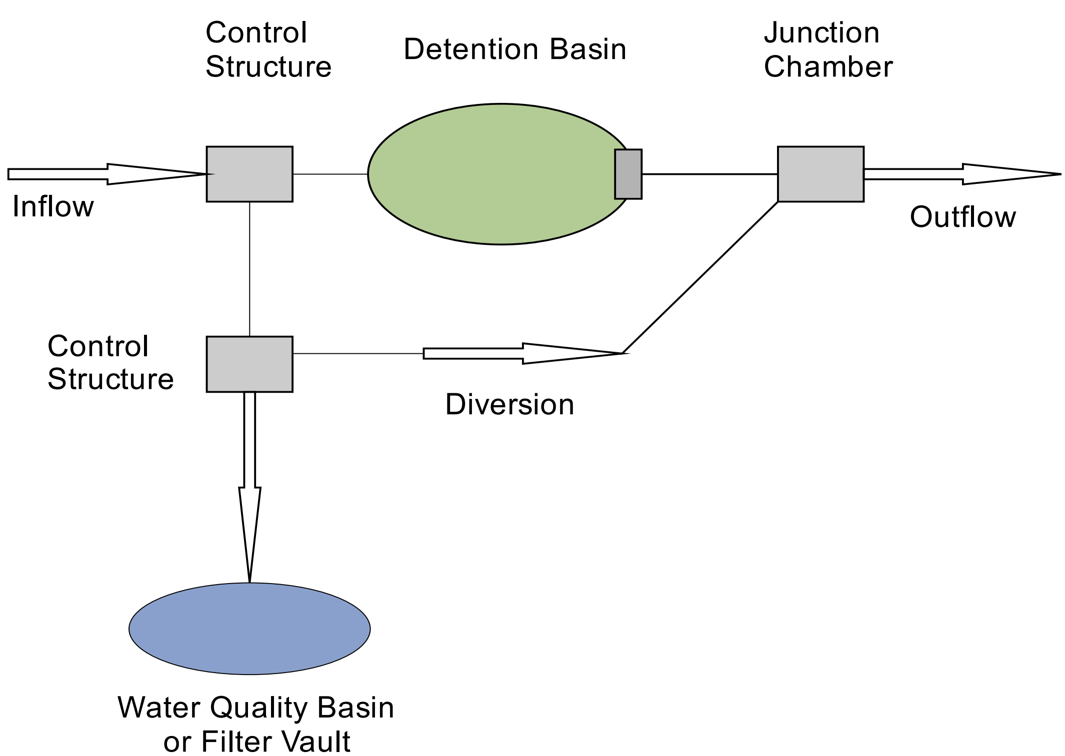
A water quality feature is added to the flow path by simply permitting the first low flows, up to the volume of inflow equal to the first-flush, to enter the water quality basin. When the desired level in the water quality basin is reached, further flow is inhibited due to the backwater effect from the developed head in the water quality basin.

Figure 5 -1: Extention Basin System Flow Path with Storm Water Treatment



An alternate layout places an additional control structure on the low flow bypass, as illustrated below:

Figure 5-2: Extention Basin System Flow Path with Storm Water Treatment



Sample Computations for the Extention Basin

A numerical proof of the improved operation of the extention basin can be provided based on the earlier equations. However, a practical proof is more easily provided by modeling the extention basin using a variety of sample cases and computing the results using readily available software.

While there are a number of software products that can be used to model the flows through the extention basin system, we have used the Army Corps of Engineers HEC-1 program here. The HEC-1 software allows a number of the necessary and detailed techniques.

For example, the development of separate hydrographs is needed for the low flow bypass and the inflow to the storage basin. HEC-1 can create these hydrographs using the diversion card. Further, in the plan with storm water treatment, the diversion cards can also be used to track the filling of the water quality basin and the subsequent re-diversion to the low flow bypass.

Of course, HEC-1 provides hydrograph creation based on watershed characteristics of curve number, lag time and area, as well as hydrograph summation and basic graphing functions.

Since the design of the extention basin is most practical by optimization techniques, we have developed a new Windows ™ interface to HEC-1 and optimization software to handle the hydraulic system design. It is necessary to optimize the diversion ratios, detention control structure components and water quality storage basin volumes until the desired final design flows are met with the minimum storage.

Description of the Sample Cases

To test our theory that the extention basin requires minimal storage while providing the required capture of the first-flush runoff, we have created a sample watershed system that undergoes development.

We assume the watershed is mildly developed in the present state with a composite SCS runoff curve number of 70.75.

We further assume that a large, new development site of about 0.20 square mile (125 acres) is contemplated, which would convert a portion of the wooded land use to essentially, all impervious areas, resulting in a new, composite curve number of 73.75.

The breakdown of existing and proposed land uses that comprise the SCS curve number is shown in Table A below:

Table A: Computation of Composite SCS Curve Number

Existing Condition			
Land Use	*Curve Number*	*Area*	*Product*
Woods	*70*	*0.950*	*66.500*
Industrial	*85*	*0.050*	*4.250*
Total	*70.75*	*1.000*	*70.750*
Proposed Condition			
Land Use	*Curve Number*	*Area*	*Product*
Woods	*70*	*0.750*	*52.500*
Industrial	*85*	*0.050*	*4.250*
New Industrial	*85*	*0.200*	*17.000*
Total	*73.75*	*1.000*	*73.750*

First-Flush of Runoff:

Since the base criterion for storm water treatment is the capture of the water quality or first-flush volume of runoff from the newly disturbed area, the volume of capture is computed to be 5.33 acre feet from 0.200 square miles, (0.5”/12 x 0.200 x 640 ac/sm).

The first-flush flow does not directly re-enter the drainage system—it is infiltrated to the soil, evaporated, or slowly drained back to the drainage system over a period of days at rates well below design storm frequencies.

It is ordinarily difficult and sometimes impossible to use the storage required for water quality to offset the storage required for peak flow control, because the first-flush volume accumulates well before the time of peak runoff. In some limited applications, it is possible to offset the storage required for peak flow reduction in very small storms, when runoff is near to one-half (½) inch.

We seek a solution where the storage required for water quality can be credited fully in the process of storm water management and peak flow reductions.

Watershed Lag:

For simplicity, we have assumed that the watershed lag is 1.0 hour. This is certainly in the order of magnitude of the watershed size of 1 square mile. In general, the analysis herein can be done with any assumed value of lag. To simplify comparisons, we further assume that the lag time remains the same in both the existing and proposed case, and is possible when the new development is not on any conceivable flow path where lag time might be measured. If a new situation develops where the lag decreases in the proposed condition, adjustment to the model can be made, easily.

Rainfall:

For simplicity, we have chosen 4.0 inches of rainfall as the design storm. This is a mid-range value since design storms range from 3.2 inches up to 7.2 inches, depending on the application. The analysis herein can be run with any design storm, but to be consistent the same rainfall is assumed in both the existing and proposed condition.

The rainfall distribution is assumed the SCS 24 hour, with Type 3 rainfall distribution and Type 2 antecedent moisture conditions. We have provided the synthetic rainfall ordinates in the computer input card file based on values commonly in use in our area.

Control Structures:

The control structures are necessary to either divert or retard flow. In the storage basin, they are composed of a low-level pipe or orifice, a mid-level spillway weir and a high level weir to control overtopping. All elevations used are relative, and it assumed the designer would use proper techniques to design individual components.

Diversion structures are devices that split flows according to certain, desired proportions. This is accomplished with flow control panels that direct flows to different directions.

Peak Flow Reduction:

Each sample case assumes that the watershed flow must be reduced to 278 cfs for the 100 year design storm (as well as all other storms). To compare methods, the storage volume necessary to produce this reduction is compiled for each case.

The following sample watershed characteristics are used to determine the inflow hydrographs.

Table B: Sample Watershed Characteristics

Item	*Existing Condition*	*Proposed Condition*	*Units*
Watershed Area	*1.0*	*1.0*	*square miles*
Watershed Lag Time	*1.0*	*1.0*	*hours*
SCS Runoff Curve Number	*70.75*	*73.75*	*(no units)*
Rainfall	*4.0*	*4.0*	*inches*
Rainfall Hydrograph	*SCS Type 3 – 24 hr.*	*SCS Type 3 – 24 hr.*	*0.1 hour inc.*
Initial Abstraction	*Computed Internally*	*Computed Internally*	*inches*
Base Flow	*0*	*0*	*cfs*

Sample Case 1A – Existing Conditions – 100 Year Storm

This case assumes a watershed without development. It is provided to illustrate actual conditions in a typical situation, with nominal values that may be encountered by design engineers.

Based on the sample input data, the following are the results of the computations:

Table 1-A: Results of Sample Case 1A – Existing Conditions – 100 Year Storm

Peak Flow	*278* cfs
Time of Peak Flow	13.17 hours

Sample Case 1B – Proposed Conditions without Control in Storage Basins – 100 Year Storm

In this case, we model the peak flows after development, where flows are left uncontrolled. The change in development is modeled by simply increasing the SCS runoff curve number of the undeveloped case, based on the addition of 125 acres of impervious area in the watershed. The remaining watershed characteristics are assumed to be unchanged by the development.

Table 2-A: Results of Sample Case 1B – Proposed Conditions

Peak Inflow (100 Yr)	*328* cfs
Time of Peak Flow (100 yr)	13.00 hours

Sample Case 2A – Control of Flows using the Conventional Detention Basin without Water Quality Storage

In this case, the after development flows are routed through a conventional detention basin system using reservoir routing techniques. The characteristics of the detention basin are as follows:

Table 2-C: Storage Volume versus Elevation / Surface Area – Conventional Detention Basin – 100 Year Storm

Elevation (feet)	*Surface Area (acres)*	*Volume (acre-feet)*
340	*0*	*0.000*
342	*0.87*	*0.553*
344	*2.17*	*3.448*
346	*2.45*	*8.065*
348	*2.74*	*13.253*
350	*3.04*	*19.030*
352	*3.36*	*25.427*

Figure 6: Case 2A – Inflow and Outflow Routing using a Conventional Detention Basin

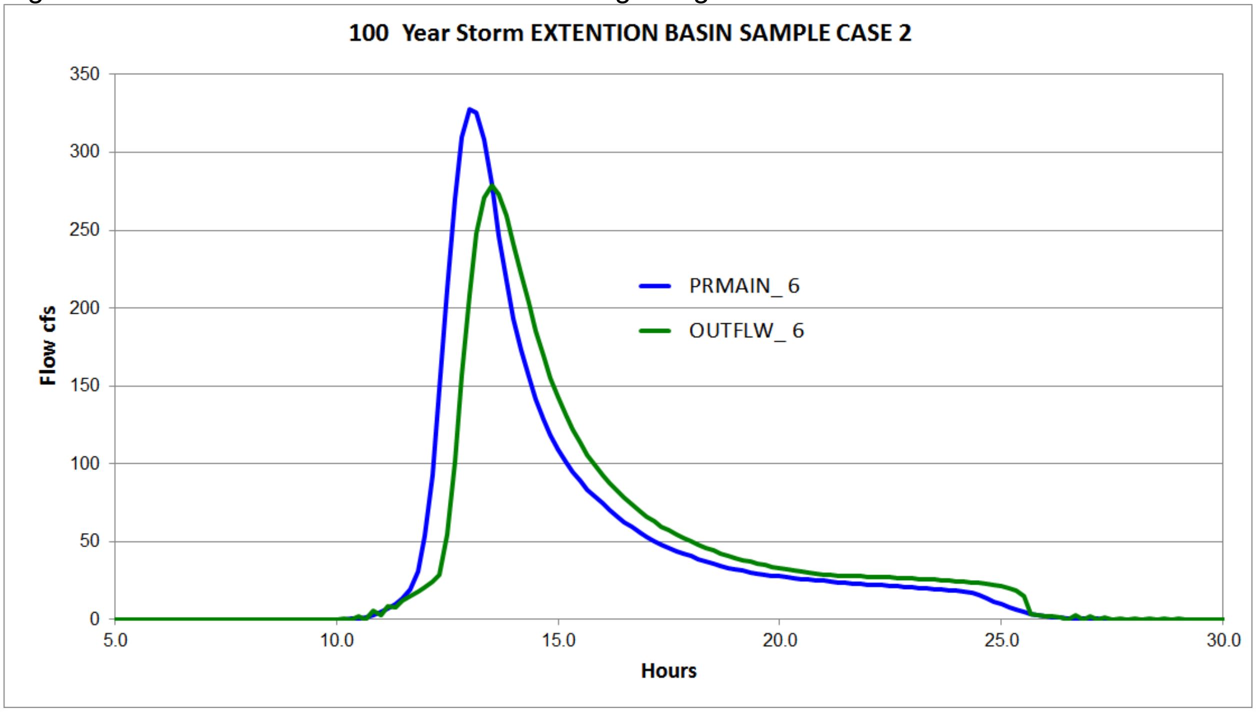


Table 2-D: Results of Sample Case 2A Proposed Conditions / Conventional Detention Basin without Water Quality Storage – 100 Year Storm

Peak Inflow	*328 cfs*
Peak Outflow	*278 cfs*
Time of Final Peak Outflow	*13.50 hours*
Peak Height in Basin	*347.96 feet*
Volume of Storage	*13.2 acre-feet*

Table 2-E - Comparison of Existing and Final Outflows for Sample Case 2A

Storm (yr)	*2*	*5*	*10*	*25*	*50*	*100*
EXMAIN Plan 1	*26.51*	*72.381*	*111.466*	*160.787*	*209.239*	*278.474*
OUTFLW Plan 1	*26.494*	*69.379*	*108.73*	*159.309*	*207.717*	*278.47*

Sample Case 2B – Control of Flows using the Conventional Detention Basin and Water Quality Storage

In this case, we attempt to control peak flows and provide the required water quality storage volume. The water quality basin is fed by a diversion of the main watershed flow until the value of 5.33 acre-feet is reached, thereafter, the remaining flow is detained in a conventional storage basin.

The flow path of this case is illustrated below:

Figure 7: Sample Case 2B – Inflow and Outflow Routing using a Conventional Detention Basin and Water Quality Storage

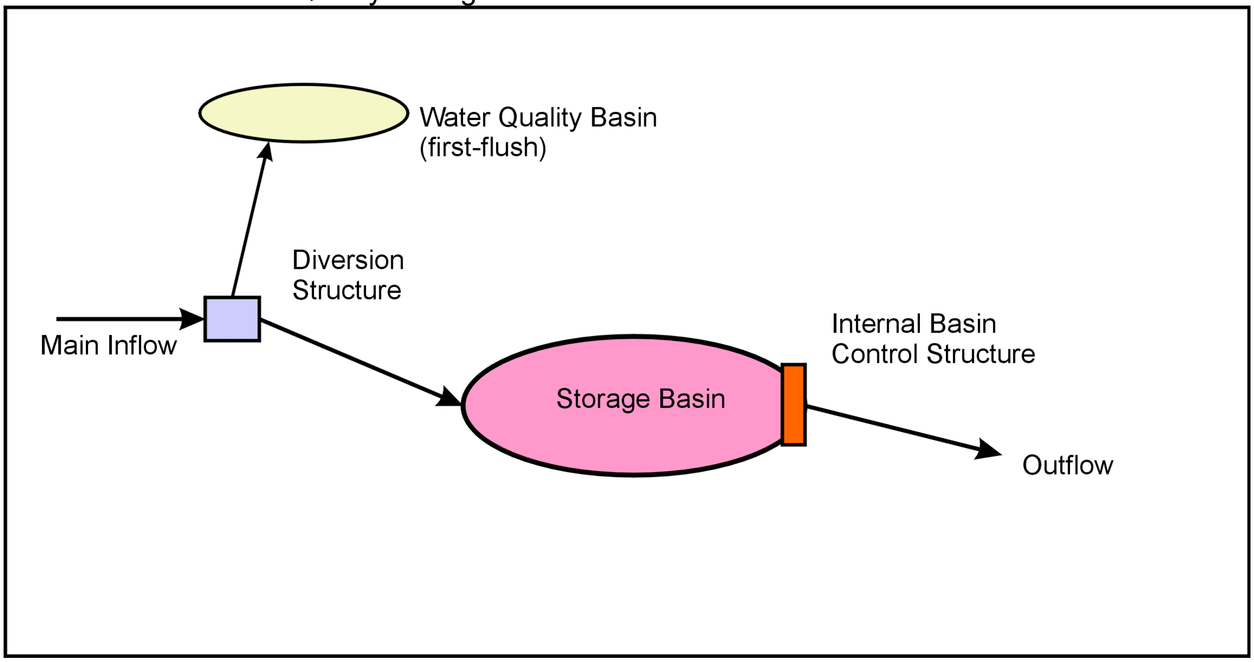


Table 2E: Results of Sample Case 2B Proposed Conditions – Conventional Peak Flow Storage and Water Quality Storage – 100 Year Storm

Peak Inflow	*328 cfs*
Peak Outflow	*278 cfs*
Time of Peak Flow	*13.50*
Peak Height in Basin	*346.62*
Volume of Storage	*9.62 acre-feet*
Volume of WQ Storage	*5.33 acre-feet*

Figure 8: Sample Case 2B Inflow / Outflow of Conventional Detention with Water Quality Storage (4 in. rainfall) – 100 Year Storm

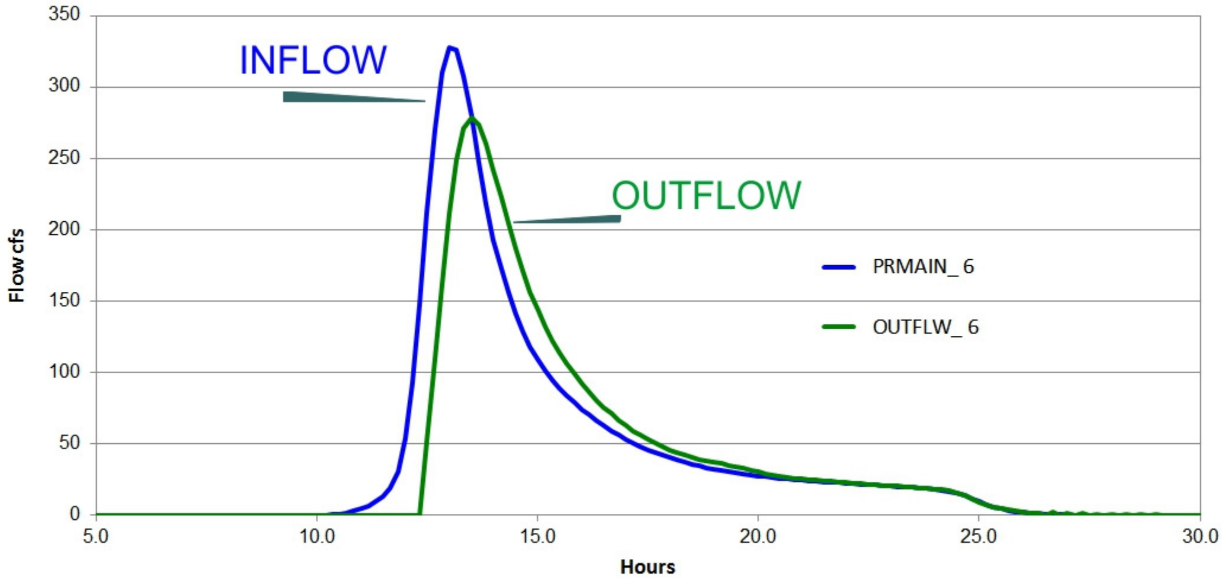


Table 2F – Comparison of Existing and Final Outflows for Sample Case 2B

Storm (yr)	*2*	*5*	*10*	*25*	*50*	*100*
EXMAIN Plan 1	*26.51*	*72.381*	*111.466*	*160.787*	*209.239*	*278.474*
OUTFLW Plan 1	*26.455*	*71.593*	*110.357*	*158.955*	*207.161*	*278.156*

Sample Case 3 – Control of Flows using the Extention Basin

In this case, the after development flows are routed through the extention basin system without any volume diverted to water quality storage. The diversions are set according to the following relationships that have been developed by our proprietary optimization software:

Table 3-A: Diversion Schedules for Case 3

Inflow (cfs)	*0*	*10.48*	*20.96*	*31.44*	*41.91*	*98.75*	*143.57*	*198.38*	*251.35*	*327.94*
Divert to Design Point (cfs)	*0*	*10.48*	*20.96*	*23*	*26*	*71.9*	*111*	*157*	*200.6*	*263.4*
Remaining Flow to Storage Basin (cfs)	*0*	*0*	*0*	*8.44*	*15.91*	*26.85*	*32.57*	*41.38*	*50.75*	*64.54*

The volume characteristics of the storage basin are as follows:

Table 3-B: Storage Volume versus Surface Area / Elevation – Extention Basin

Elevation (feet)	*Surface Area (acres)*	*Volume (acre-feet)*
340	*0*	*0.000*
342	*0.87*	*0.553*
344	*2.17*	*3.448*
346	*2.45*	*8.065*
348	*2.74*	*13.253*
350	*3.04*	*19.030*
352	*3.36*	*25.427*

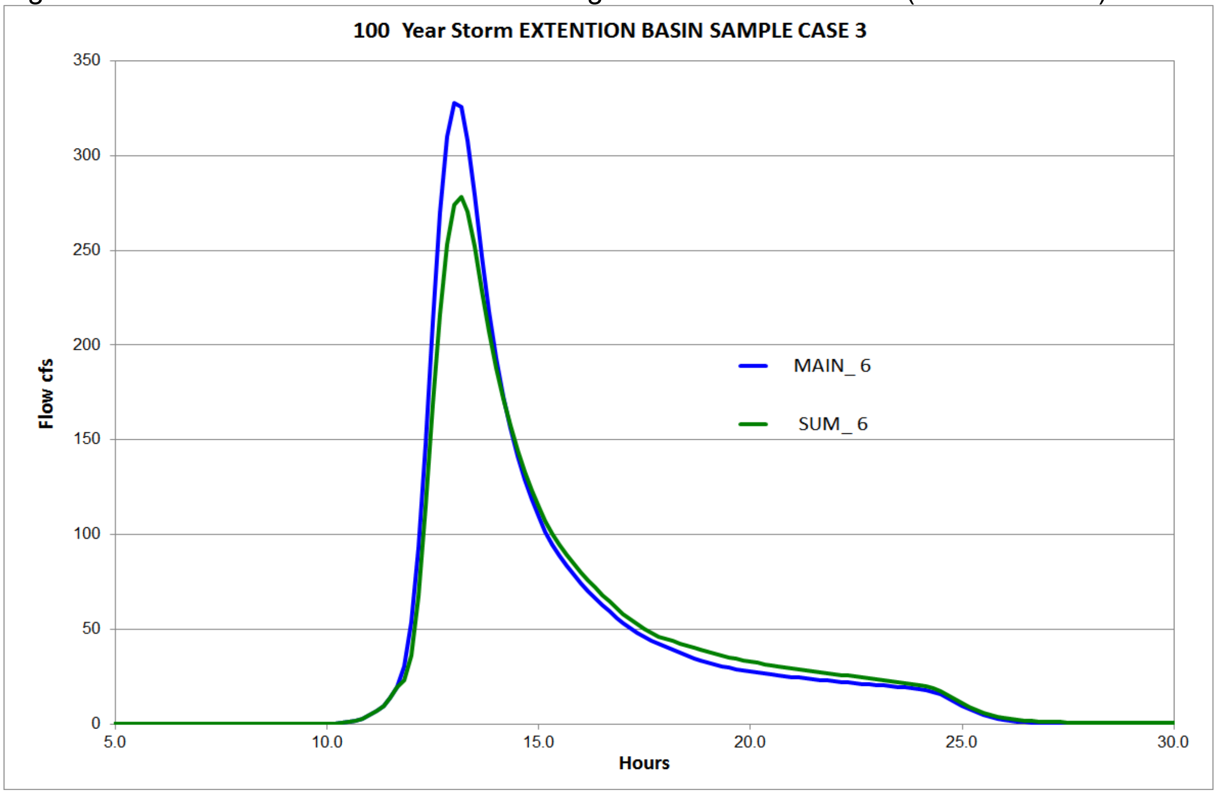
Table 3-B: Results of Sample Case 3 Summary of Storage / Extention Basin – 100 Year Storm

Peak Inflow	*328 cfs*
Peak Flow	*278 cfs*
Time of Peak Final Outflow	*13.17*
Peak Height in Basin	*345.13*
Volume of Detention Storage	*6.0 acre-feet*
Volume of Water Quality Storage	*0*

Table: 3-C Comparison of Existing Flows and Final Outflows

Storm (yr)	*2*	*5*	*10*	*25*	*50*	*100*
EXMAIN Plan 1	*26.51*	*72.381*	*111.466*	*160.787*	*209.239*	*278.474*
SUM Plan 1	*26.359*	*72.312*	*111.443*	*160.658*	*209.129*	*278.442*

Figure 9: Case 3: Inflow and Outflow Routing of the Extention Basin (4 in. of rainfall)



Discussion of the Extention Basin for Sample Cases 2 and 3

In sample case 2A, we used a conventional detention basin computation that brought all the peaks flows to existing targets and required 13.2 acre-feet of storage. In contrast, sample case 3 provides clear proof that the extention basin can provide the same across the board reductions in peak flows with less than one-half the storage (6.0 acre-feet).

This remarkable result is evident graphically (Fig. 9)—the outflow hydrograph follows the rising limb of the inflow hydrograph and the need for storage is minimized accordingly.

Given the need to capture the water quality volume or first flush, and remembering that the first-flush capture basin is really only effective in reducing peak flows when the main flows are small, we can integrate the storm water control and water quality control in our highly effective, extention basin. This is illustrated in Sample Case 4, below:

Sample Case 4 – Control of Flows using the Extention Basin and Storm Water Treatment

In our final Sample Case 4, a water quality basin is added to the extention basin system and we attempt to control a wide range of storm frequencies. Flows are diverted to the water quality basin until the pre-computed water quality volume or first-flush volume of ½ inch of runoff over the newly developed portion of the watershed is reached.

A portion of the flow is conveyed to the water quality basin by imposing a diversion structure. The initial flows are directed to the water quality basin, thereafter, when the basin is full, flows are naturally re-directed to the final design point by the principle of hydraulic balancing.

Our sample case requires that 5.33 acre-feet of first-flush runoff be stored in the water quality basin. This value is placed in field 2 of the DT input card file of our HEC-1 model.

Most importantly, this case examines a range of flows from 1.84 inches of rainfall, to 4.0 inches of rainfall. This is accomplished in HEC-1 by creating 6 "ratios" as evidenced by the JR multiratio card. The ratios of each plan range from 0.46 to 1.00 and operate in HEC-1 by re-computing the entire model for each ratio times the design rainfall of 4.0 inches on the PB card.

For Case 4, we have assumed that the 100-year storm is 4.0 inches of rainfall in 24 hours, and have provided rainfalls for the 2, 5, 10, 25 and 50-year storms by the multiratio plans. In fact, 100-year storms are closer to 7 inches of rainfall in the northeast; however, we use the lower value to maintain consistency with our goal of using mid range flows whenever possible in the sample cases. Any reasonable value of rainfall can be used to compare the effectiveness of the extention basin to the detention basin since the computations are always relative.

The following are the steps in the final computation over a range of flows:

Table 4-A: Storage Volume versus Elevation – Extention Basin

Elevation (feet)	*Surface Area (acres)*	*Volume (acre-feet)*
340	*0*	*0.000*
342	*0.87*	*0.553*
344	*2.17*	*3.448*
346	*2.45*	*8.065*
348	*2.74*	*13.253*
350	*3.04*	*19.030*
352	*3.36*	*25.427*

Table 4-B: Storage Volume versus Elevation – Water Quality Basin

Elevation (feet)	*Surface Area (acres)*	*Volume (acre-feet)*
340	*0.00*	*0.00*
342	*0.20*	*0.13*
344	*0.53*	*0.83*
346	*1.06*	*2.39*
348	*1.93*	*5.33*

Table 4-C: Diversion Schedules for Case 4

Inflow (cfs)	*0*	*10.478*	*20.956*	*31.435*	*41.913*	*98.747*	*143.571*	*198.379*	*251.348*	*327.941*
Divert to Design Point (cfs)	*0*	*10.478*	*20.956*	*28*	*35*	*73.1*	*111*	*160*	*204.8*	*266.5*
Remaining Flow to Storage Basin (cfs)	*0*	*0*	*0*	*3.435*	*6.913*	*25.647*	*32.571*	*38.379*	*46.548*	*61.441*

Table 4-D: Computation of Water Quality / First Flush Volume Required:

New Impervious -- Disturbed Area	*125*	*acres*
Rainfall to be Captured	*0.5*	*inches*
Computed Volume to be Captured	*5.33*	*acre-feet*

Table 4-E: Sample Case 4 - Summary of Peak Flows by Storm Frequency

Storm Frequency (year)	*Existing Flow (cfs)*	*Proposed Inflow (cfs)*	*Extention Basin Outflow (cfs)*
100	*278.47*	*328*	*278.47*
50	*209.24*	*251*	*209.12*
25	*160.79*	*198*	*160.44*
10	*111.47*	*144*	*111.36*
5	*72.38*	*99*	*72.09*
2	*26.51*	*42*	*26.07*

Table 4-F: Results of Sample Case 4 - Summary of Storage

Peak Inflow	*328 cfs*
Peak Flow	*278 cfs*
Time of Peak Final Outflow	*13.17*
Peak Height in Basin	*344.63*
Volume of Detention Storage	*4.847 acre-feet*
Volume of Water Quality Storage	*5.33 acre-feet*

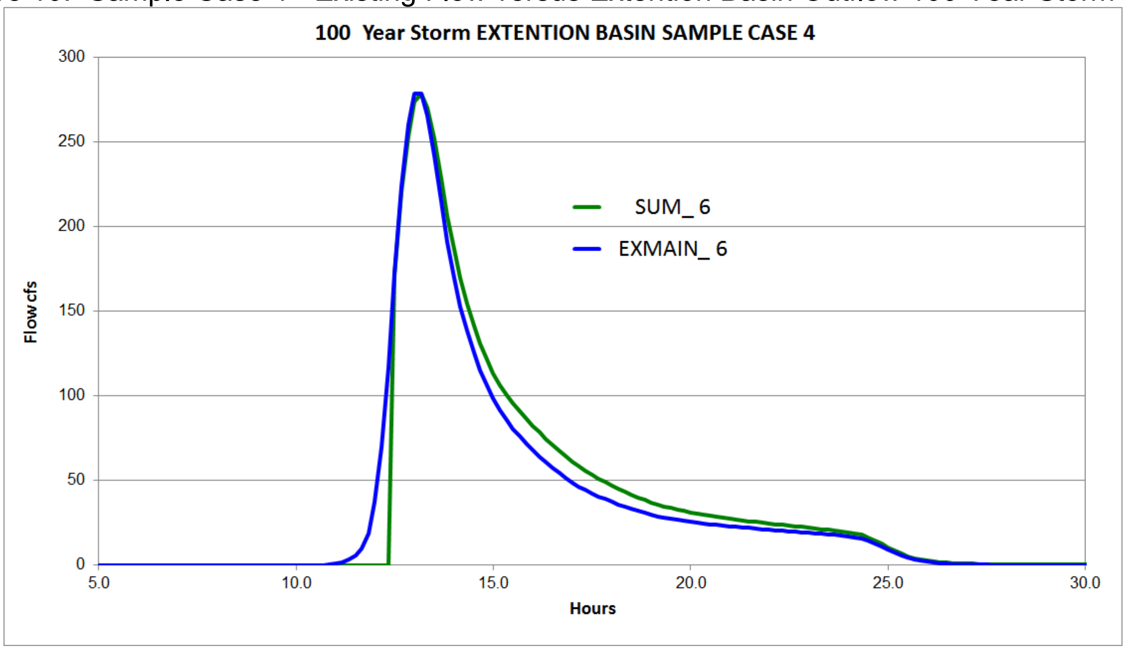
Discussion of the Extention Basin Efficiency:

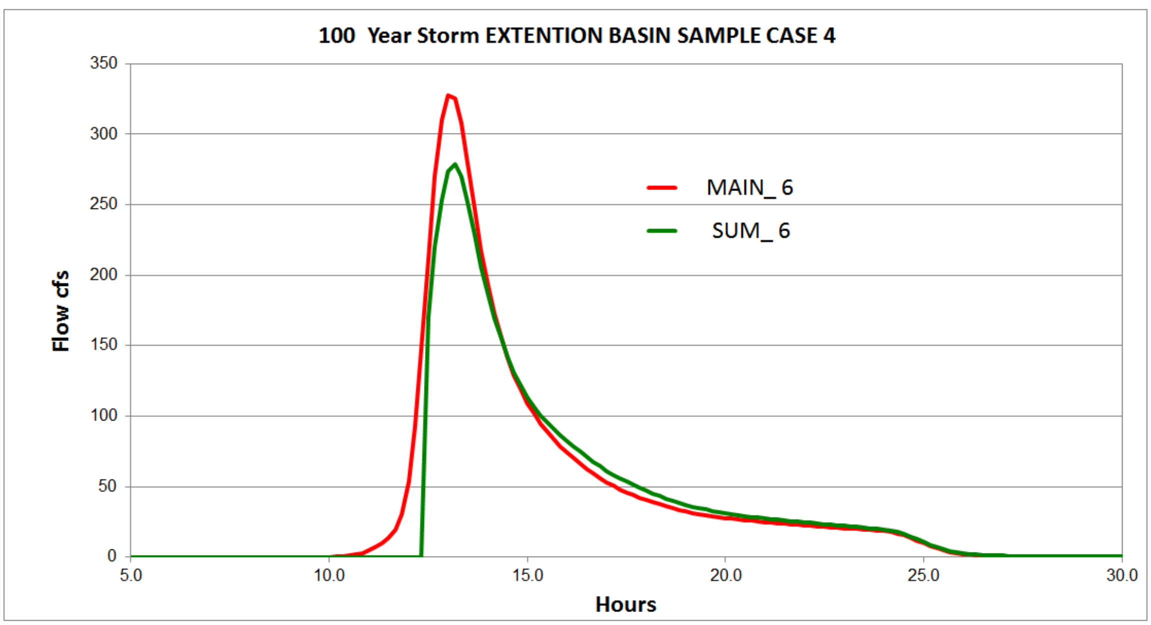
It is clear from the summary Table 4-E, that the extention basin system has reduced peak flows to almost match the original flows.

For example, the 100-year storm runoff is 278 cfs both in the existing and proposed cases, even though the development in the watershed has increased to flows 328 cfs. The 2-year storm has been reduced from the proposed flow of 42 to 26.07 cfs—slightly below the existing peak flow of 26.51 cfs.

The graph of the results of the existing flows as compared to the final flows is indicated below:

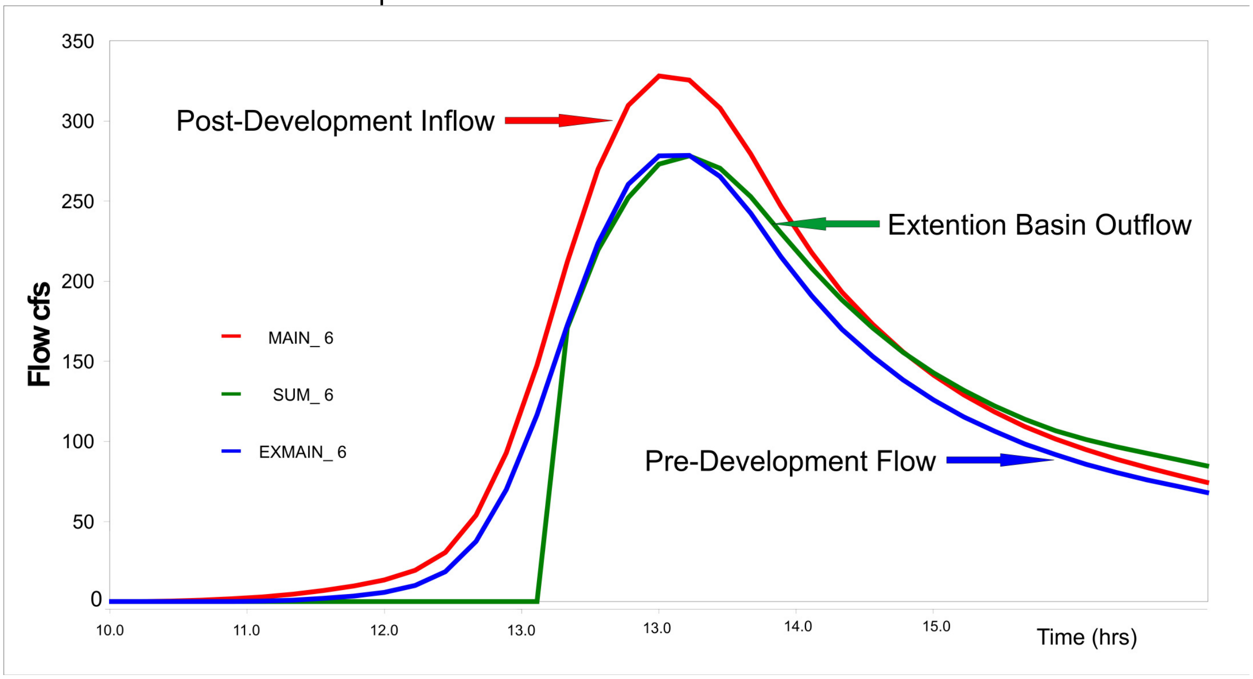
Figure 10: Sample Case 4 - Existing Flow versus Extention Basin Outflow 100 Year Storm





A close-up comparison of the final results along with the proposed, after-development inflows for the 100-year storm is shown on the graph below:

Figure 11: Close-Up Comparison of Existing Flows / Proposed Flows and Extention Basin Outflows Sample Case 4



It is immediately apparent from the graphs that the extention basin accomplishes an additional important task. In Figure 11, the initial, existing inflow hydrograph is nearly identical to the extention basin outflows.

The reduction of outflow lag between inflow and outflow is an added, environmental benefit of the extention basin since any natural drainage system is less likely to be affected by the change in timing. Further, we have eliminated unknown flooding affects associated with timing of peak flows from other watersheds.

Sample Case Summary:

Each sample case performed the task of reducing all the post-development peak flow to the design peak flows using a storage basin. The conventional storage basin system using standard reservoir routing techniques computed the storage at 13.2 acre-feet (9.62 acre-feet for case 2B), to these values we must add 5.33 acre feet required for first-flush storage.

The extention basin performed very much better, requiring only 4.847 acre feet of storage to control peak flows and 5.33 acre feet for storm water treatment for a total storage of 10.18 acre-feet.

The Table below summarizes the storage required for each sample case.

Table 5: Comparison of Storage Requirements for the Sample Cases

Sample Case	*Description*	*Storage Volume for Peak Flow Control (acre-feet)*	*Storage Volume for Water Quality Treatment (acre-feet)*	*Total Storage Volume Required (acre-feet)*
1-A	*Existing Conditions*	*n.a.*	*n.a.*	*n.a.*
1-B	*After Development Conditions*	*n.a.*	*n.a.*	*n.a.*
2-A	*Conventional Detention Basin – No Water Quality Treatment*	***13.2***	*0*	*13.2*
2-B	*Conventional Detention Basin with Water Quality Treatment*	*9.62*	*5.33*	***14.95***
3	*Extention Basin No Water Quality Treatment*	***6.0***	*0*	*6.0*
4	*Extention Basin with Water Quality Treatment*	*4.847*	*5.33*	***10.18***

Table 6: Summary of Peak Flows and Peak Time vs Storm Frequency for each Sample Case

Sample Case	**Storm Frequency (years)**					
	100	**50**	**25**	**10**	**5**	**2**
	Peak Flows (cfs) / Peak Time (hrs)					
1-A	**278/13.17**	**209/13.17**	**161/13.17**	**111/13.17**	**72/13.17**	**27/13.33**
1-B	**328/13.00**	**251/13.00**	**198/13.17**	**144/13.17**	**99/13.17**	**42/13.33**
2-A	**278/13.50**	**207.5/13.50**	**159/13.67**	**108.5/13.83**	**69.2/14.00**	**26.5/14.50**
2-B	**278/13.50**	**207/13.50**	**159/13.67**	**110.4/13.67**	**71.6/13.83**	**26.5/14.50**
3	**278/13.17**	**209/13.17**	**161/13.17**	**111/13.17**	**72/13.17**	**26.4/13.33**
4	**278/13.00**	**209/13.17**	**160/13.17**	**111/13.17**	**72/13.33**	**26/14.33**

Conclusion:

The extention basin provides the control of the range of peak flows using less storage than a conventional retention or detention basin. This phenomenon occurs because we have found a method to “tune” the system to minimize the storage requirement.

The extention basin described in our sample case requires only about 68% of the total storage of a conventional stormwater system where water quality treatment is also required (Case 4 vs. Case 2-B), and controls flows over a very wide range of storm frequencies.

When the capture of the first-flush of storm water is required for water quality treatment and control of peak flows is required over a wide range of storm frequencies, the total storage volume can be minimized by the use of an extention basin that uses storage volumes close to the theoretical minimum storage volume (Case 4).

It is noteworthy that the extention basin requires less than half the detention storage of a conventional system, (6.0/13.2 = 45%. Case 3 vs. Case 2A). It does this while simultaneously reducing peak flows for all storms to the pre-development levels.

Close inspection of the resulting hydrographs indicates that the time to peak of the extention basin outflow is very close to the time to peak of the pre-development hydrograph. This feature can make developments “transparent” in the environment as watershed timing will not be affected to the degree of a standard detention system.

The technique for computing these detailed volumes is straightforward—and can be computed by trial and error or optimization methods.

Since the expected savings of up to 50% in storage is so great, the additional design time required to optimize and fine-tune the computations is well worth the effort.

References:

1. U.S. Army Corps of Engineers HEC-1 Flood Hydrograph Package,Users Manual, September 1981, The Hydrologic Engineering Center, 609 Second Street, Davis, California 95616

2. U.S. Army Corps of Engineers HEC-1 Computer Program

3. Urban Hydrology for Small Watersheds, USDA, Soil Conservation Service, Technical Release 55 June 1986

4. RGM HEC 2000 Computer Program www.hec-1.com.

5. www.extentionbasin.com for commercial applications of the extention basin.

Appendix:

The following pages include shortened printouts of the HEC-1 computer program for each of the Sample cases. The printouts have been edited to reduce blank lines, headers, and repetitive or non-essential matter that accompany the HEC-1 program output.

The input cards have not been edited, therefore, the sample input data can be used independently to test or reproduce these results.

HEC-1 Printouts

CASE 1 A AND B

```
 ****************************************                                                      ***************************************
 *                                      *                                                      *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                                                      *    U.S. ARMY CORPS OF ENGINEERS     *
 *        JUN 1998 AND FEB 2010         *                                                      *    HYDROLOGIC ENGINEERING CENTER    *
 *            VERSION 4.1R              *                                                      *          609 SECOND STREET          *
 *      RGMHEC2000 WWW.HEC-1.COM        *                                                      *       DAVIS, CALIFORNIA 95616       *
 *  RUN DATE   09MAY11  TIME  22:13:44  *                                                      *           (916) 756-1104            *
 *                                      *                                                      *                                     *
 ****************************************                                                      ***************************************

                                                 X     X  XXXXXXX   XXXXX          X
                                                 X     X  X        X     X        XX
                                                 X     X  X        X               X
                                                 XXXXXXX  XXXX     X       XXXXX   X
                                                 X     X  X        X               X
                                                 X     X  X        X     X         X
                                                 X     X  XXXXXXX   XXXXX         XXX

            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL    LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                                      HEC-1 INPUT                                                PAGE  1

           LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

              1          ID  RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
              2          ID  CASE 1A + CASE 1B -   EXISTING AND PROPOSED CONDITION NO CONTROL
              3          IO       5       5
                         *DIAGRAM
              4          IT      10                    200                    2000
              5          IN       6            000
              6          KK  BEFORE
              7          KM  BEFORE DEVELOPMENT
              8          KO       5                              21
              9          PB       4
             10          PC  .00100 0.00200 0.00300 0.00400 0.00500 0.00600 0.00700 0.00800 0.00900 0.01000
             11          PC  .01100 0.01200 0.01300 0.01400 0.01500 0.01600 0.01700 0.01800 0.01900 0.02000
             12          PC  .02101 0.02203 0.02307 0.02412 0.02519 0.02627 0.02737 0.02848 0.02961 0.03075
             13          PC  .03191 0.03308 0.03427 0.03547 0.03669 0.03792 0.03917 0.04043 0.04171 0.04300
             14          PC  .04431 0.04563 0.04697 0.04832 0.04969 0.05107 0.05247 0.05388 0.05531 0.05675
             15          PC  .05821 0.05968 0.06117 0.06267 0.06419 0.06572 0.06727 0.06883 0.07041 0.07200
             16          PC  .07363 0.07530 0.07703 0.07880 0.08063 0.08250 0.08443 0.08640 0.08843 0.09050
             17          PC  .09263 0.09480 0.09703 0.09930 0.10163 0.10400 0.10643 0.10890 0.11143 0.11400
             18          PC  .11666 0.11943 0.12232 0.12532 0.12844 0.13167 0.13502 0.13846 0.14206 0.14575
             19          PC  .14956 0.15348 0.15752 0.16167 0.16594 0.17032 0.17482 0.17943 0.18416 0.18900
             20          PC  .19402 0.19928 0.20478 0.21052 0.21650 0.22272 0.22918 0.23588 0.24282 0.25000
             21          PC  .25776 0.26644 0.27604 0.28656 0.29800 0.31430 0.33940 0.37330 0.41600 0.50000
             22          PC  .58400 0.62670 0.66060 0.68570 0.70200 0.71344 0.72396 0.73356 0.74224 0.75000
             23          PC  .75718 0.76412 0.77082 0.77728 0.78350 0.78948 0.79522 0.80072 0.80598 0.81100
             24          PC  .81584 0.82057 0.82518 0.82968 0.83406 0.83833 0.84248 0.84652 0.85044 0.85425
             25          PC  .85794 0.86152 0.86498 0.86833 0.87156 0.87468 0.87768 0.88057 0.88334 0.88600
             26          PC  .88858 0.89110 0.89358 0.89600 0.89838 0.90070 0.90298 0.90520 0.90738 0.90950
             27          PC  .91158 0.91360 0.91558 0.91750 0.91938 0.92120 0.92298 0.92470 0.92638 0.92800
             28          PC  .92959 0.93117 0.93273 0.93428 0.93581 0.93733 0.93883 0.94032 0.94179 0.94325
             29          PC  .94469 0.94612 0.94753 0.94893 0.95031 0.95168 0.95303 0.95437 0.95569 0.95700
             30          PC  .95829 0.95958 0.96085 0.96211 0.96336 0.96460 0.96582 0.96704 0.96824 0.96944
             31          PC  .97062 0.97179 0.97295 0.97410 0.97523 0.97636 0.97747 0.97858 0.97967 0.98075
             32          PC  .98182 0.98288 0.98392 0.98496 0.98598 0.98700 0.98800 0.98899 0.98997 0.99094
             33          PC  .99189 0.99284 0.99377 0.99470 0.99561 0.99651 0.99740 0.99828 0.99914 1.00000
             34          BA       1
             35          LS           70.75
             36          UD       1
             37          KK   AFTER
             38          KM  AFTER DEVELOPMENT
             39          BA       1
             40          LS           73.75
             41          UD       1
             42          ZZ
1
               SCHEMATIC DIAGRAM OF STREAM NETWORK
 INPUT
  LINE      (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

   NO.      (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

     6      BEFORE
                 .
                 .
    37           .       AFTER

 (***) RUNOFF ALSO COMPUTED AT THIS LOCATION
```

```
1****************************************                       ****************************************
 *                                      *                       *                                      *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)  *                       *    U.S. ARMY CORPS OF ENGINEERS      *
 *        JUN 1998 AND FEB 2010         *                       *    HYDROLOGIC ENGINEERING CENTER     *
 *            VERSION 4.1R              *                       *          609 SECOND STREET           *
 *      RGMHEC2000 WWW.HEC-1.COM        *                       *       DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09MAY11  TIME  22:13:44  *                       *           (916) 756-1104             *
 *                                      *                       *                                      *
 ****************************************                       ****************************************

                          RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
                          CASE 1A + CASE 1B -   EXISTING AND PROPOSED CONDITION NO CONTROL

    3 IO         OUTPUT CONTROL VARIABLES
                       IPRNT          5  PRINT CONTROL
                       IPLOT          5  PLOT CONTROL
                       QSCAL         0.  HYDROGRAPH PLOT SCALE

      IT         HYDROGRAPH TIME DATA
                        NMIN         10  MINUTES IN COMPUTATION INTERVAL
                       IDATE      1    0  STARTING DATE
                       ITIME       0000  STARTING TIME
                          NQ        200  NUMBER OF HYDROGRAPH ORDINATES
                      NDDATE      2    0  ENDING DATE
                      NDTIME       0910  ENDING TIME
                       ICENT         20  CENTURY MARK

                 COMPUTATION INTERVAL     .17 HOURS
                      TOTAL TIME BASE   33.17 HOURS

           ENGLISH UNITS
                DRAINAGE AREA         SQUARE MILES
                PRECIPITATION DEPTH   INCHES
                LENGTH, ELEVATION     FEET
                FLOW                  CUBIC FEET PER SECOND
                STORAGE VOLUME        ACRE-FEET
                SURFACE AREA          ACRES
                TEMPERATURE           DEGREES FAHRENHEIT

    8 KO         OUTPUT CONTROL VARIABLES
                       IPRNT          5  PRINT CONTROL
                       IPLOT          5  PLOT CONTROL
                       QSCAL         0.  HYDROGRAPH PLOT SCALE
                       IPNCH          0  PUNCH COMPUTED HYDROGRAPH
                        IOUT         21  SAVE HYDROGRAPH ON THIS UNIT
                       ISAV1          1  FIRST ORDINATE PUNCHED OR SAVED
                       ISAV2        200  LAST ORDINATE PUNCHED OR SAVED
                      TIMINT       .167  TIME INTERVAL IN HOURS
1
```

RUNOFF SUMMARY
FLOW IN CUBIC FEET PER SECOND
TIME IN HOURS, AREA IN SQUARE MILES

	OPERATION	STATION	PEAK FLOW	TIME OF PEAK	AVERAGE FLOW FOR MAXIMUM PERIOD 6-HOUR	24-HOUR	72-HOUR	BASIN AREA	MAXIMUM STAGE	TIME OF MAX STAGE
+	HYDROGRAPH AT	BEFORE	278.47	13.17	119.	37.	27.	1.00		
+	HYDROGRAPH AT	AFTER	327.94	13.00	137.	42.	31.	1.00		

*** NORMAL END OF HEC-1 ***

CASE 2A

```
*****************************************                                                             ****************************************
 *                                       *                                                             *                                      *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                             *    U.S. ARMY CORPS OF ENGINEERS      *
 *        JUN 1998 AND FEB 2010          *                                                             *    HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1R                *                                                             *          609 SECOND STREET           *
 *       RGMHEC2000 WWW.HEC-1.COM        *                                                             *       DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09MAY11  TIME  22:09:26   *                                                             *           (916) 756-1104             *
 *                                       *                                                             *                                      *
 *****************************************                                                             ****************************************

                                                  X     X  XXXXXXX   XXXXX          X
                                                  X     X  X        X     X        XX
                                                  X     X  X        X               X
                                                  XXXXXXX  XXXX     X       XXXXX   X
                                                  X     X  X        X               X
                                                  X     X  X        X     X         X
                                                  X     X  XXXXXXX   XXXXX         XXX

            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                                    HEC-1 INPUT                                                    PAGE  1

           LINE           ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

              1           ID  RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
              2           ID  CASE 2A  AFTER DEVELOPMENT -  CONVENTIONAL DETENTION NO WATER QUALITY
              3           IO       1       2
                          *DIAGRAM
              4           IT      10                     200                     2000
              5           IN       6             000
              6           JR    PREC    0.46    0.60    0.69    0.79    0.88    1.00
              7           KK  PRMAIN
              8           KO       5       5                      21
              9           KM  WATERSHED 1
             10           PB       4
             11           PC  .00100 0.00200 0.00300 0.00400 0.00500 0.00600 0.00700 0.00800 0.00900 0.01000
             12           PC  .01100 0.01200 0.01300 0.01400 0.01500 0.01600 0.01700 0.01800 0.01900 0.02000
             13           PC  .02101 0.02203 0.02307 0.02412 0.02519 0.02627 0.02737 0.02848 0.02961 0.03075
             14           PC  .03191 0.03308 0.03427 0.03547 0.03669 0.03792 0.03917 0.04043 0.04171 0.04300
             15           PC  .04431 0.04563 0.04697 0.04832 0.04969 0.05107 0.05247 0.05388 0.05531 0.05675
             16           PC  .05821 0.05968 0.06117 0.06267 0.06419 0.06572 0.06727 0.06883 0.07041 0.07200
             17           PC  .07363 0.07530 0.07703 0.07880 0.08063 0.08250 0.08443 0.08640 0.08843 0.09050
             18           PC  .09263 0.09480 0.09703 0.09930 0.10163 0.10400 0.10643 0.10890 0.11143 0.11400
             19           PC  .11666 0.11943 0.12232 0.12532 0.12844 0.13167 0.13502 0.13846 0.14206 0.14575
             20           PC  .14956 0.15348 0.15752 0.16167 0.16594 0.17032 0.17482 0.17943 0.18416 0.18900
             21           PC  .19402 0.19928 0.20478 0.21052 0.21650 0.22272 0.22918 0.23588 0.24282 0.25000
             22           PC  .25776 0.26644 0.27604 0.28656 0.29800 0.31430 0.33940 0.37330 0.41600 0.50000
             23           PC  .58400 0.62670 0.66060 0.68570 0.70200 0.71344 0.72396 0.73356 0.74224 0.75000
             24           PC  .75718 0.76412 0.77082 0.77728 0.78350 0.78948 0.79522 0.80072 0.80598 0.81100
             25           PC  .81584 0.82057 0.82518 0.82968 0.83406 0.83833 0.84248 0.84652 0.85044 0.85425
             26           PC  .85794 0.86152 0.86498 0.86833 0.87156 0.87468 0.87768 0.88057 0.88334 0.88600
             27           PC  .88858 0.89110 0.89358 0.89600 0.89838 0.90070 0.90298 0.90520 0.90738 0.90950
             28           PC  .91158 0.91360 0.91558 0.91750 0.91938 0.92120 0.92298 0.92470 0.92638 0.92800
             29           PC  .92959 0.93117 0.93273 0.93428 0.93581 0.93733 0.93883 0.94032 0.94179 0.94325
             30           PC  .94469 0.94612 0.94753 0.94893 0.95031 0.95168 0.95303 0.95437 0.95569 0.95700
             31           PC  .95829 0.95958 0.96085 0.96211 0.96336 0.96460 0.96582 0.96704 0.96824 0.96944
             32           PC  .97062 0.97179 0.97295 0.97410 0.97523 0.97636 0.97747 0.97858 0.97967 0.98075
             33           PC  .98182 0.98288 0.98392 0.98496 0.98598 0.98700 0.98800 0.98899 0.98997 0.99094
             34           PC  .99189 0.99284 0.99377 0.99470 0.99561 0.99651 0.99740 0.99828 0.99914 1.00000
             35           BA       1
             36           LS           73.75
             37           UD       1
             38           KK  OUTFLW
             39           KO       5       5                      21
             40           RS       1    ELEV     340
             41           SA       0    0.83    2.17    2.45    2.74    3.04    3.36
             42           SE     340     342     344     346     348     350     352
             43           SL     340    3.08     .61      .5
             44           SS  343.48    7.45   3.337     1.5
             45           ST     351      10     3.1     1.5
             46           KK  EXMAIN
             47           KO       5       5                      21
             48           KM  WATERSHED 1 - PRE-DEVELOPMENT
             49           BA       1
             50           LS           70.75
             51           UD       1
                 SCHEMATIC DIAGRAM OF STREAM NETWORK
 INPUT
  LINE       (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

   NO.       (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

     7       PRMAIN
                 V
                 V
    38       OUTFLW
                 .
                 .
    46           .      EXMAIN

 (***) RUNOFF ALSO COMPUTED AT THIS LOCATION
```

```
1*****************************************                                                    ****************************************
 *                                        *                                                   *                                      *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)    *                                                   *    U.S. ARMY CORPS OF ENGINEERS      *
 *        JUN 1998 AND FEB 2010           *                                                   *    HYDROLOGIC ENGINEERING CENTER     *
 *            VERSION 4.1R                *                                                   *         609 SECOND STREET            *
 *       RGMHEC2000 WWW.HEC-1.COM         *                                                   *       DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09MAY11  TIME  22:09:26    *                                                   *           (916) 756-1104             *
 *                                        *                                                   *                                      *
 *****************************************                                                    ****************************************

                           RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
                           CASE 2A  AFTER DEVELOPMENT -  CONVENTIONAL DETENTION NO WATER QUALITY

    3 IO         OUTPUT CONTROL VARIABLES
                       IPRNT          1  PRINT CONTROL
                       IPLOT          2  PLOT CONTROL
                       QSCAL         0.  HYDROGRAPH PLOT SCALE

      IT         HYDROGRAPH TIME DATA
                        NMIN         10  MINUTES IN COMPUTATION INTERVAL
                       IDATE      1    0  STARTING DATE
                       ITIME       0000  STARTING TIME
                          NQ        200  NUMBER OF HYDROGRAPH ORDINATES
                      NDDATE      2    0  ENDING DATE
                      NDTIME       0910  ENDING TIME
                       ICENT         20  CENTURY MARK

                    COMPUTATION INTERVAL     .17 HOURS
                         TOTAL TIME BASE   33.17 HOURS

           ENGLISH UNITS
                DRAINAGE AREA         SQUARE MILES
                PRECIPITATION DEPTH   INCHES
                LENGTH, ELEVATION     FEET
                FLOW                  CUBIC FEET PER SECOND
                STORAGE VOLUME        ACRE-FEET
                SURFACE AREA          ACRES
                TEMPERATURE           DEGREES FAHRENHEIT

      JP         MULTI-PLAN OPTION
                       NPLAN          1  NUMBER OF PLANS

      JR         MULTI-RATIO OPTION
                     RATIOS OF PRECIPITATION
                      .46       .60       .69       .79       .88      1.00


1
```

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

OPERATION	STATION	AREA	PLAN		RATIOS APPLIED TO PRECIPITATION					
					RATIO 1 .46	RATIO 2 .60	RATIO 3 .69	RATIO 4 .79	RATIO 5 .88	RATIO 6 1.00
HYDROGRAPH AT										
+	PRMAIN	1.000	1	FLOW	41.91	98.75	143.57	198.38	251.35	327.94
				TIME	13.33	13.17	13.17	13.17	13.00	13.00
ROUTED TO										
+	OUTFLW	1.000	1	FLOW	26.49	69.38	108.73	159.31	207.72	278.47
				TIME	14.50	14.00	13.83	13.67	13.50	13.50
			** PEAK STAGES IN FEET **							
			1	STAGE	343.09	344.77	345.54	346.36	347.05	347.96
				TIME	14.50	14.00	13.83	13.67	13.50	13.50
HYDROGRAPH AT										
+	EXMAIN	1.000	1	FLOW	26.51	72.38	111.47	160.79	209.24	278.47
				TIME	13.33	13.17	13.17	13.17	13.17	13.17

1 **SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION OUTFLW**
(PEAKS SHOWN ARE FOR INTERNAL TIME STEP USED DURING BREACH FORMATION)

PLAN 1	INITIAL VALUE	SPILLWAY CREST	TOP OF DAM
ELEVATION	340.00	343.48	351.00
STORAGE	.00	2.43	22.15
OUTFLOW	.00	28.11	562.65

RATIO OF PMF	MAXIMUM RESERVOIR W.S.ELEV	MAXIMUM DEPTH OVER DAM	MAXIMUM STORAGE AC-FT	MAXIMUM OUTFLOW CFS	DURATION OVER TOP HOURS	TIME OF MAX OUTFLOW HOURS	TIME OF FAILURE HOURS
.46	343.09	.00	1.799	26.49	.00	14.50	.00
.60	344.77	.00	5.162	69.38	.00	14.00	.00
.69	345.54	.00	6.943	108.73	.00	13.83	.00
.79	346.36	.00	8.949	159.31	.00	13.67	.00
.88	347.05	.00	10.717	207.72	.00	13.50	.00
1.00	347.96	.00	13.150	278.47	.00	13.50	.00

```
 *** NORMAL END OF HEC-1 ***
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CASE 2B

```
****************************************                                                            ****************************************
 *                                      *                                                            *                                      *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                           *    U.S. ARMY CORPS OF ENGINEERS      *
 *        JUN 1998 AND FEB 2010         *                                                            *    HYDROLOGIC ENGINEERING CENTER     *
 *            VERSION 4.1R              *                                                            *          609 SECOND STREET           *
 *       RGMHEC2000 WWW.HEC-1.COM       *                                                            *       DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09MAY11  TIME  22:08:03   *                                                           *           (916) 756-1104             *
 *                                      *                                                            *                                      *
 ****************************************                                                            ****************************************

                                                  X     X  XXXXXXX   XXXXX          X
                                                  X     X  X        X     X        XX
                                                  X     X  X        X               X
                                                  XXXXXXX  XXXX     X       XXXXX   X
                                                  X     X  X        X               X
                                                  X     X  X        X     X         X
                                                  X     X  XXXXXXX   XXXXX         XXX

            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                                    HEC-1 INPUT                                                    PAGE  1

           LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

              1          ID  RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
              2          ID  CASE 2B  AFTER DEVELOPMENT -  CONVENTIONAL DETENTION W/ WATER QUALITY
              3          IO       1       2
                         *DIAGRAM
              4          IT      10                  200                    2000
              5          IN       6           000
              6          JR    PREC    0.46    0.60    0.69    0.79    0.88    1.00
              7          KK  PRMAIN
              8          KO       5       5                      21
              9          KM  WATERSHED 1
             10          PB       4
             11          PC  .00100 0.00200 0.00300 0.00400 0.00500 0.00600 0.00700 0.00800 0.00900 0.01000
             12          PC  .01100 0.01200 0.01300 0.01400 0.01500 0.01600 0.01700 0.01800 0.01900 0.02000
             13          PC  .02101 0.02203 0.02307 0.02412 0.02519 0.02627 0.02737 0.02848 0.02961 0.03075
             14          PC  .03191 0.03308 0.03427 0.03547 0.03669 0.03792 0.03917 0.04043 0.04171 0.04300
             15          PC  .04431 0.04563 0.04697 0.04832 0.04969 0.05107 0.05247 0.05388 0.05531 0.05675
             16          PC  .05821 0.05968 0.06117 0.06267 0.06419 0.06572 0.06727 0.06883 0.07041 0.07200
             17          PC  .07363 0.07530 0.07703 0.07880 0.08063 0.08250 0.08443 0.08640 0.08843 0.09050
             18          PC  .09263 0.09480 0.09703 0.09930 0.10163 0.10400 0.10643 0.10890 0.11143 0.11400
             19          PC  .11666 0.11943 0.12232 0.12532 0.12844 0.13167 0.13502 0.13846 0.14206 0.14575
             20          PC  .14956 0.15348 0.15752 0.16167 0.16594 0.17032 0.17482 0.17943 0.18416 0.18900
             21          PC  .19402 0.19928 0.20478 0.21052 0.21650 0.22272 0.22918 0.23588 0.24282 0.25000
             22          PC  .25776 0.26644 0.27604 0.28656 0.29800 0.31430 0.33940 0.37330 0.41600 0.50000
             23          PC  .58400 0.62670 0.66060 0.68570 0.70200 0.71344 0.72396 0.73356 0.74224 0.75000
             24          PC  .75718 0.76412 0.77082 0.77728 0.78350 0.78948 0.79522 0.80072 0.80598 0.81100
             25          PC  .81584 0.82057 0.82518 0.82968 0.83406 0.83833 0.84248 0.84652 0.85044 0.85425
             26          PC  .85794 0.86152 0.86498 0.86833 0.87156 0.87468 0.87768 0.88057 0.88334 0.88600
             27          PC  .88858 0.89110 0.89358 0.89600 0.89838 0.90070 0.90298 0.90520 0.90738 0.90950
             28          PC  .91158 0.91360 0.91558 0.91750 0.91938 0.92120 0.92298 0.92470 0.92638 0.92800
             29          PC  .92959 0.93117 0.93273 0.93428 0.93581 0.93733 0.93883 0.94032 0.94179 0.94325
             30          PC  .94469 0.94612 0.94753 0.94893 0.95031 0.95168 0.95303 0.95437 0.95569 0.95700
             31          PC  .95829 0.95958 0.96085 0.96211 0.96336 0.96460 0.96582 0.96704 0.96824 0.96944
             32          PC  .97062 0.97179 0.97295 0.97410 0.97523 0.97636 0.97747 0.97858 0.97967 0.98075
             33          PC  .98182 0.98288 0.98392 0.98496 0.98598 0.98700 0.98800 0.98899 0.98997 0.99094
             34          PC  .99189 0.99284 0.99377 0.99470 0.99561 0.99651 0.99740 0.99828 0.99914 1.00000
             35          BA       1
             36          LS           73.75
             37          UD       1
             38          KK    THRU
             39          KM  DIVERT  FIRST FLUSH TO-WQ BASIN - USE MAX. VOLUME TO LIMIT DIVERSION
             40          KO       5       2                      21
             41          DT   TO-WQ    5.33
             42          DI       0      10      20      50      80     100     180     300
             43          DQ       0      10      20      50      80     100     180     300
             44          KK  OUTFLW
             45          KO       5       5                      21
             46          RS       1    ELEV     340
             47          SA       0    0.83    2.17    2.45    2.74    3.04    3.36
             48          SE     340     342     344     346     348     350     352
             49          SL     340     5.5     .61      .5
             50          SS     342     6.3   3.337     1.5
             51          ST     351      10     3.1     1.5
             52          KK  EXMAIN
             53          KO       5       5                      21
             54          KM  WATERSHED 1 - PRE-DEVELOPMENT
             55          BA       1
             56          LS           70.75
             57          UD       1
             58          ZZ
1
```

```
               SCHEMATIC DIAGRAM OF STREAM NETWORK
 INPUT
  LINE      (V) ROUTING         (--->) DIVERSION OR PUMP FLOW

   NO.      (.) CONNECTOR       (<---) RETURN OF DIVERTED OR PUMPED FLOW

     7      PRMAIN
                .
                .
    41          .------->   TO-WQ
    38         THRU
                V
                V
    44      OUTFLW
                .
                .
    52          .      EXMAIN

 (***) RUNOFF ALSO COMPUTED AT THIS LOCATION
1*****************************************                                                ***************************************
 *                                       *                                                *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                *   U.S. ARMY CORPS OF ENGINEERS      *
 *       JUN 1998 AND FEB 2010           *                                                *   HYDROLOGIC ENGINEERING CENTER     *
 *           VERSION 4.1R                *                                                *         609 SECOND STREET           *
 *      RGMHEC2000 WWW.HEC-1.COM         *                                                *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09MAY11  TIME  22:08:03   *                                                *          (916) 756-1104             *
 *                                       *                                                *                                     *
 *****************************************                                                ***************************************

                         RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
                         CASE 2B  AFTER DEVELOPMENT -  CONVENTIONAL DETENTION W/ WATER QUALITY

    3 IO         OUTPUT CONTROL VARIABLES
                       IPRNT          1  PRINT CONTROL
                       IPLOT          2  PLOT CONTROL
                       QSCAL         0.  HYDROGRAPH PLOT SCALE

      IT         HYDROGRAPH TIME DATA
                        NMIN         10  MINUTES IN COMPUTATION INTERVAL
                       IDATE      1   0  STARTING DATE
                       ITIME       0000  STARTING TIME
                          NQ        200  NUMBER OF HYDROGRAPH ORDINATES
                      NDDATE      2   0  ENDING DATE
                      NDTIME       0910  ENDING TIME
                      ICENT          20  CENTURY MARK

                   COMPUTATION INTERVAL     .17 HOURS
                        TOTAL TIME BASE   33.17 HOURS

          ENGLISH UNITS
               DRAINAGE AREA         SQUARE MILES
               PRECIPITATION DEPTH   INCHES
               LENGTH, ELEVATION     FEET
               FLOW                  CUBIC FEET PER SECOND
               STORAGE VOLUME        ACRE-FEET
               SURFACE AREA          ACRES
               TEMPERATURE           DEGREES FAHRENHEIT

      JP         MULTI-PLAN OPTION
                       NPLAN          1  NUMBER OF PLANS

      JR         MULTI-RATIO OPTION
                     RATIOS OF PRECIPITATION
                     .46       .60       .69       .79       .88      1.00
```

PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

OPERATION	STATION	AREA	PLAN		RATIOS APPLIED TO PRECIPITATION RATIO 1 .46	RATIO 2 .60	RATIO 3 .69	RATIO 4 .79	RATIO 5 .88	RATIO 6 1.00
HYDROGRAPH AT										
+	PRMAIN	1.000	1	FLOW	41.91	98.75	143.57	198.38	251.35	327.94
				TIME	13.33	13.17	13.17	13.17	13.00	13.00
DIVERSION TO										
+	TO-WQ	1.000	1	FLOW	41.91	95.64	108.21	118.66	139.28	147.67
				TIME	13.33	13.00	12.67	12.50	12.50	12.33
HYDROGRAPH AT										
+	THRU	1.000	1	FLOW	28.29	96.75	143.57	198.38	251.35	327.94
				TIME	14.33	13.33	13.17	13.17	13.00	13.00
ROUTED TO										
+	OUTFLW	1.000	1	FLOW	26.45	71.59	110.36	158.96	207.16	278.16
				TIME	14.50	13.83	13.67	13.67	13.50	13.50
			** PEAK STAGES IN FEET **							
			1	STAGE	340.97	343.10	343.94	344.83	345.60	346.62
				TIME	14.50	13.83	13.67	13.67	13.50	13.50
HYDROGRAPH AT										
+	EXMAIN	1.000	1	FLOW	26.51	72.38	111.47	160.79	209.24	278.47
				TIME	13.33	13.17	13.17	13.17	13.17	13.17

```
1                          SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION   OUTFLW
                      (PEAKS SHOWN ARE FOR INTERNAL TIME STEP USED  DURING BREACH FORMATION)


      PLAN  1 ..............               INITIAL VALUE     SPILLWAY CREST     TOP OF DAM
                             ELEVATION        340.00             342.00           351.00
                             STORAGE             .00                .55            22.15
                             OUTFLOW             .00              38.05           656.86


                  RATIO     MAXIMUM      MAXIMUM    MAXIMUM    MAXIMUM    DURATION    TIME OF     TIME OF
                   OF      RESERVOIR      DEPTH     STORAGE    OUTFLOW    OVER TOP   MAX OUTFLOW  FAILURE
                   PMF      W.S.ELEV    OVER DAM     AC-FT       CFS        HOURS       HOURS       HOURS

                    .46      340.97        .00        .062      26.45        .00       14.50         .00
                    .60      343.10        .00       1.810      71.59        .00       13.83         .00
                    .69      343.94        .00       3.325     110.36        .00       13.67         .00
                    .79      344.83        .00       5.286     158.96        .00       13.67         .00
                    .88      345.60        .00       7.093     207.16        .00       13.50         .00
                   1.00      346.62        .00       9.617     278.16        .00       13.50         .00

 *** NORMAL END OF HEC-1 ***
```

CASE 3

```
****************************************                                   ***************************************
 *                                        *                                   *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)    *                                   *    U.S. ARMY CORPS OF ENGINEERS     *
 *        JUN 1998 AND FEB 2010           *                                   *    HYDROLOGIC ENGINEERING CENTER    *
 *            VERSION 4.1R                *                                   *          609 SECOND STREET          *
 *      RGMHEC2000 WWW.HEC-1.COM          *                                   *       DAVIS, CALIFORNIA 95616       *
 *  RUN DATE   09MAY11  TIME  22:06:59    *                                   *          (916) 756-1104             *
 *                                        *                                   *                                     *
 ****************************************                                   ***************************************

                                    X     X  XXXXXXX   XXXXX          X
                                    X     X  X        X     X        XX
                                    X     X  X        X               X
                                    XXXXXXX  XXXX     X       XXXXX   X
                                    X     X  X        X               X
                                    X     X  X        X     X         X
                                    X     X  XXXXXXX   XXXXX         XXX

            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL    LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM
```

```
1                                                      HEC-1 INPUT                                            PAGE  1

           LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

              1          ID  RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
              2          ID  CASE 3 - EXTENTION BASIN CONTROL SYSTEM - AFTER DEVELOPMENT
              3          IO       5       5
                         *DIAGRAM
              4          IT      10                      200                     2000
              5          IN       6             000
              6          JR    PREC    0.46    0.60    0.69    0.79    0.88    1.00
              7          KK    MAIN
              8          KO       5       5                       21
              9          KM  WATERSHED 1
             10          PB       4
             11          PC  .00100 0.00200 0.00300 0.00400 0.00500 0.00600 0.00700 0.00800 0.00900 0.01000
             12          PC  .01100 0.01200 0.01300 0.01400 0.01500 0.01600 0.01700 0.01800 0.01900 0.02000
             13          PC  .02101 0.02203 0.02307 0.02412 0.02519 0.02627 0.02737 0.02848 0.02961 0.03075
             14          PC  .03191 0.03308 0.03427 0.03547 0.03669 0.03792 0.03917 0.04043 0.04171 0.04300
             15          PC  .04431 0.04563 0.04697 0.04832 0.04969 0.05107 0.05247 0.05388 0.05531 0.05675
             16          PC  .05821 0.05968 0.06117 0.06267 0.06419 0.06572 0.06727 0.06883 0.07041 0.07200
             17          PC  .07363 0.07530 0.07703 0.07880 0.08063 0.08250 0.08443 0.08640 0.08843 0.09050
             18          PC  .09263 0.09480 0.09703 0.09930 0.10163 0.10400 0.10643 0.10890 0.11143 0.11400
             19          PC  .11666 0.11943 0.12232 0.12532 0.12844 0.13167 0.13502 0.13846 0.14206 0.14575
             20          PC  .14956 0.15348 0.15752 0.16167 0.16594 0.17032 0.17482 0.17943 0.18416 0.18900
             21          PC  .19402 0.19928 0.20478 0.21052 0.21650 0.22272 0.22918 0.23588 0.24282 0.25000
             22          PC  .25776 0.26644 0.27604 0.28656 0.29800 0.31430 0.33940 0.37330 0.41600 0.50000
             23          PC  .58400 0.62670 0.66060 0.68570 0.70200 0.71344 0.72396 0.73356 0.74224 0.75000
             24          PC  .75718 0.76412 0.77082 0.77728 0.78350 0.78948 0.79522 0.80072 0.80598 0.81100
             25          PC  .81584 0.82057 0.82518 0.82968 0.83406 0.83833 0.84248 0.84652 0.85044 0.85425
             26          PC  .85794 0.86152 0.86498 0.86833 0.87156 0.87468 0.87768 0.88057 0.88334 0.88600
             27          PC  .88858 0.89110 0.89358 0.89600 0.89838 0.90070 0.90298 0.90520 0.90738 0.90950
             28          PC  .91158 0.91360 0.91558 0.91750 0.91938 0.92120 0.92298 0.92470 0.92638 0.92800
             29          PC  .92959 0.93117 0.93273 0.93428 0.93581 0.93733 0.93883 0.94032 0.94179 0.94325
             30          PC  .94469 0.94612 0.94753 0.94893 0.95031 0.95168 0.95303 0.95437 0.95569 0.95700
             31          PC  .95829 0.95958 0.96085 0.96211 0.96336 0.96460 0.96582 0.96704 0.96824 0.96944
             32          PC  .97062 0.97179 0.97295 0.97410 0.97523 0.97636 0.97747 0.97858 0.97967 0.98075
             33          PC  .98182 0.98288 0.98392 0.98496 0.98598 0.98700 0.98800 0.98899 0.98997 0.99094
             34          PC  .99189 0.99284 0.99377 0.99470 0.99561 0.99651 0.99740 0.99828 0.99914 1.00000
             35          BA       1
             36          LS           73.75
             37          UD       1
             38          KK  LOFLOW
             39          KM  FLOWS TO STORAGE BASIN
             40          KO       5       5                       21
             41          DT  BYPASS
```

```
          42           DI       0   10.48   20.96   31.44   41.91   98.75  143.57  198.38  251.35  327.94
          43           DQ       0   10.48   20.96      23      26    71.9     111     157   200.6   263.4

          44           KK  OUTFLW
          45           KO       5       5                      21
          46           RS       1    ELEV     340
          47           SA       0    0.83    2.17    2.45    2.74    3.04    3.36
          48           SE     340     342     344     346     348     350     352
          49           SL     340     .05     .61      .5
          50           SS   343.3     4.3   3.337     1.5
          51           ST     351      10     3.1     1.5
          52           KK  RETURN
          53           KM  RETURN DIVERTED FLOWS
          54           KO       5       5                      21
          55           DR  BYPASS
          56           KK     SUM
          57           KO       5       5                      21
          58           HC       2
          59           KK  EXMAIN
          60           KO       5                              21
          61           KM  WATERSHED 1 - PRE-DEVE LOPMENT
          62           BA       1
          63           LS           70.75
          64           UD       1
          65           ZZ
1
                 SCHEMATIC DIAGRAM OF STREAM NETWORK
 INPUT
  LINE      (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

   NO.      (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

     7        MAIN
                 .
                 .
    41           .------->  BYPASS
    38      LOFLOW
                 V
                 V
    44      OUTFLW
                 .
                 .
    55           .           .<-------  BYPASS
    52           .      RETURN
                 .           .
                 .           .
    56         SUM...........
                 .
                 .
    59           .      EXMAIN

 (***) RUNOFF ALSO COMPUTED AT THIS LOCATION
1*****************************************                                                   ***************************************
 *                                       *                                                   *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                   *    U.S. ARMY CORPS OF ENGINEERS     *
 *        JUN 1998 AND FEB 2010          *                                                   *    HYDROLOGIC ENGINEERING CENTER    *
 *            VERSION 4.1R               *                                                   *          609 SECOND STREET          *
 *       RGMHEC2000 WWW.HEC-1.COM        *                                                   *       DAVIS, CALIFORNIA 95616       *
 *  RUN DATE   09MAY11  TIME  22:06:59   *                                                   *           (916) 756-1104            *
 *                                       *                                                   *                                     *
 *****************************************                                                   ***************************************

                         RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
                         CASE 3 - EXTENTION BASIN CONTROL SYSTEM - AFTER DEVELOPMENT

    3 IO         OUTPUT CONTROL VARIABLES
                       IPRNT          5  PRINT CONTROL
                       IPLOT          5  PLOT CONTROL
                       QSCAL         0.  HYDROGRAPH PLOT SCALE

      IT         HYDROGRAPH TIME DATA
                        NMIN         10  MINUTES IN COMPUTATION INTERVAL
                       IDATE      1    0  STARTING DATE
                       ITIME       0000  STARTING TIME
                          NQ        200  NUMBER OF HYDROGRAPH ORDINATES
                      NDDATE      2    0  ENDING DATE
                      NDTIME       0910  ENDING TIME
                       ICENT         20  CENTURY MARK

                    COMPUTATION INTERVAL     .17 HOURS
                         TOTAL TIME BASE   33.17 HOURS

          ENGLISH UNITS
               DRAINAGE AREA         SQUARE MILES
               PRECIPITATION DEPTH   INCHES
               LENGTH, ELEVATION     FEET
               FLOW                  CUBIC FEET PER SECOND
               STORAGE VOLUME        ACRE-FEET
               SURFACE AREA          ACRES
               TEMPERATURE           DEGREES FAHRENHEIT

      JP         MULTI-PLAN OPTION
                       NPLAN          1  NUMBER OF PLANS

      JR         MULTI-RATIO OPTION
                     RATIOS OF PRECIPITATION
                     .46       .60       .69       .79       .88      1.00
```

```
            PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
                              FLOWS IN CUBIC FEET PER SECOND,  AREA IN SQUARE MILES
                                                TIME TO PEAK IN HOURS

                                                           RATIOS APPLIED TO PRECIPITATION
 OPERATION       STATION     AREA    PLAN             RATIO 1  RATIO 2  RATIO 3  RATIO 4  RATIO 5  RATIO 6
                                                          .46      .60      .69      .79      .88     1.00

 HYDROGRAPH AT
+                   MAIN    1.000      1   FLOW       41.91    98.75   143.57   198.38   251.35   327.94
                                           TIME       13.33    13.17    13.17    13.17    13.00    13.00

 DIVERSION TO
+                 BYPASS    1.000      1   FLOW       26.00    71.90   111.00   157.00   200.60   263.40
                                           TIME       13.33    13.17    13.17    13.17    13.00    13.00

 HYDROGRAPH AT
+                 LOFLOW    1.000      1   FLOW       15.91    26.85    32.57    41.38    50.75    64.54
                                           TIME       13.33    13.17    13.17    13.17    13.00    13.00

 ROUTED TO
+                 OUTFLW    1.000      1   FLOW         .42    12.08    16.95    22.13    27.36    36.12
                                           TIME       14.83    15.33    15.50    15.00    14.67    14.17

                                     ** PEAK STAGES IN FEET **
                                       1   STAGE     343.02   344.17   344.39   344.61   344.82   345.13
                                           TIME       15.17    15.33    15.50    15.00    14.67    14.17

 HYDROGRAPH AT
+                 RETURN     .000      1   FLOW       26.00    71.90   111.00   157.00   200.60   263.40
                                           TIME       13.33    13.17    13.17    13.17    13.00    13.00

  2 COMBINED AT
+                    SUM    1.000      1   FLOW       26.36    72.31   111.44   160.66   209.13   278.44
                                           TIME       13.33    13.17    13.17    13.17    13.17    13.17

 HYDROGRAPH AT
+                 EXMAIN    1.000      1   FLOW       26.51    72.38   111.47   160.79   209.24   278.47
                                           TIME       13.33    13.17    13.17    13.17    13.17    13.17
1                                  SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION   OUTFLW
                              (PEAKS SHOWN ARE FOR INTERNAL TIME STEP USED  DURING BREACH FORMATION)


      PLAN  1 ..............                INITIAL VALUE     SPILLWAY CREST     TOP OF DAM
                                ELEVATION       340.00            343.30           351.00
                                STORAGE            .00              2.12            22.15
                                OUTFLOW            .00               .44           307.40


                      RATIO     MAXIMUM      MAXIMUM    MAXIMUM    MAXIMUM    DURATION    TIME OF     TIME OF
                       OF      RESERVOIR      DEPTH     STORAGE    OUTFLOW    OVER TOP   MAX OUTFLOW  FAILURE
                      PMF       W.S.ELEV    OVER DAM     AC-FT       CFS       HOURS       HOURS       HOURS

                       .46       343.02        .00       1.693        .43        .00        15.17        .00
                       .60       344.17        .00       3.812      12.08        .00        15.33        .00
                       .69       344.39        .00       4.315      16.95        .00        15.50        .00
                       .79       344.61        .00       4.806      22.13        .00        15.00        .00
                       .88       344.82        .00       5.268      27.36        .00        14.67        .00
                      1.00       345.13        .00       5.992      36.12        .00        14.17        .00

 *** NORMAL END OF HEC-1 ***
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CASE 4

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*****************************************                                                ***************************************
 *                                       *                                                *                                     *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                *   U.S. ARMY CORPS OF ENGINEERS      *
 *        JUN 1998 AND FEB 2010          *                                                *   HYDROLOGIC ENGINEERING CENTER     *
 *            VERSION 4.1R               *                                                *         609 SECOND STREET           *
 *      RGMHEC2000 WWW.HEC-1.COM         *                                                *      DAVIS, CALIFORNIA 95616        *
 *  RUN DATE   09MAY11  TIME  22:03:42   *                                                *          (916) 756-1104             *
 *                                       *                                                *                                     *
 *****************************************                                                ***************************************

                                                X     X  XXXXXXX   XXXXX          X
                                                X     X  X        X     X        XX
                                                X     X  X        X               X
                                                XXXXXXX  XXXX     X       XXXXX   X
                                                X     X  X        X               X
                                                X     X  X        X     X         X
                                                X     X  XXXXXXX   XXXXX         XXX

            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM

1                                                      HEC-1 INPUT                                          PAGE  1

           LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

             1           ID  RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
             2           ID  CASE 4 - EXTENTION BASIN CONTROL SYSTEM - AFTER DEVELOPMENT
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```
  3          IO      5       5
             *DIAGRAM
  4          IT     10                  2000                   2000
  5          IN      6              000
  6          JR   PREC    0.46    0.60    0.69    0.79    0.88    1.00
  7          KK   MAIN
  8          KO      5       5                      21
  9          KM  WATERSHED 1
 10          PB      4
 11          PC  .00100 0.00200 0.00300 0.00400 0.00500 0.00600 0.00700 0.00800 0.00900 0.01000
 12          PC  .01100 0.01200 0.01300 0.01400 0.01500 0.01600 0.01700 0.01800 0.01900 0.02000
 13          PC  .02101 0.02203 0.02307 0.02412 0.02519 0.02627 0.02737 0.02848 0.02961 0.03075
 14          PC  .03191 0.03308 0.03427 0.03547 0.03669 0.03792 0.03917 0.04043 0.04171 0.04300
 15          PC  .04431 0.04563 0.04697 0.04832 0.04969 0.05107 0.05247 0.05388 0.05531 0.05675
 16          PC  .05821 0.05968 0.06117 0.06267 0.06419 0.06572 0.06727 0.06883 0.07041 0.07200
 17          PC  .07363 0.07530 0.07703 0.07880 0.08063 0.08250 0.08443 0.08640 0.08843 0.09050
 18          PC  .09263 0.09480 0.09703 0.09930 0.10163 0.10400 0.10643 0.10890 0.11143 0.11400
 19          PC  .11666 0.11943 0.12232 0.12532 0.12844 0.13167 0.13502 0.13846 0.14206 0.14575
 20          PC  .14956 0.15348 0.15752 0.16167 0.16594 0.17032 0.17482 0.17943 0.18416 0.18900
 21          PC  .19402 0.19928 0.20478 0.21052 0.21650 0.22272 0.22918 0.23588 0.24282 0.25000
 22          PC  .25776 0.26644 0.27604 0.28656 0.29800 0.31430 0.33940 0.37330 0.41600 0.50000
 23          PC  .58400 0.62670 0.66060 0.68570 0.70200 0.71344 0.72396 0.73356 0.74224 0.75000
 24          PC  .75718 0.76412 0.77082 0.77728 0.78350 0.78948 0.79522 0.80072 0.80598 0.81100
 25          PC  .81584 0.82057 0.82518 0.82968 0.83406 0.83833 0.84248 0.84652 0.85044 0.85425
 26          PC  .85794 0.86152 0.86498 0.86833 0.87156 0.87468 0.87768 0.88057 0.88334 0.88600
 27          PC  .88858 0.89110 0.89358 0.89600 0.89838 0.90070 0.90298 0.90520 0.90738 0.90950
 28          PC  .91158 0.91360 0.91558 0.91750 0.91938 0.92120 0.92298 0.92470 0.92638 0.92800
 29          PC  .92959 0.93117 0.93273 0.93428 0.93581 0.93733 0.93883 0.94032 0.94179 0.94325
 30          PC  .94469 0.94612 0.94753 0.94893 0.95031 0.95168 0.95303 0.95437 0.95569 0.95700
 31          PC  .95829 0.95958 0.96085 0.96211 0.96336 0.96460 0.96582 0.96704 0.96824 0.96944
 32          PC  .97062 0.97179 0.97295 0.97410 0.97523 0.97636 0.97747 0.97858 0.97967 0.98075
 33          PC  .98182 0.98288 0.98392 0.98496 0.98598 0.98700 0.98800 0.98899 0.98997 0.99094
 34          PC  .99189 0.99284 0.99377 0.99470 0.99561 0.99651 0.99740 0.99828 0.99914 1.00000
 35          BA      1
 36          LS          73.75
 37          UD      1
 38          KK   THRU
 39          KM  DIVERT  FIRST FLUSH TO-WQ BASIN - USE MAX. VOLUME TO LIMIT DIVERSION
 40          KO      5       2                      21
 41          DT   TO-WQ    5.33
 42          DI      0      10      20      50      80     100     180     300
 43          DQ      0      10      20      50      80     100     180     300
 44          KK  LOFLOW
 45          KM  FLOWS TO STORAGE BASIN
 46          KO      5       5                      21
 47          DT  BYPASS
 48          DI      0  10.478  20.956  31.435  41.913  98.747 143.571 198.379 251.348 327.941
 49          DQ      0  10.478  20.956      28      35    73.1     111     160   204.8   266.5
 50          KK  OUTFLW
 51          KO      5       5                      21
 52          RS      1    ELEV     340
 53          SA      0    0.83    2.17    2.45    2.74    3.04    3.36
 54          SE    340     342     344     346     348     350     352
 55          SL    340     .05     .61      .5
 56          SS  342.8    3.88   3.337     1.5
 57          ST    351      10     3.1     1.5
 58          KK  RETURN
 59          KM  RETURN DIVERTED FLOWS
 60          KO      5       5                      21
 61          DR  BYPASS
 62          KK    SUM
 63          KO      5       5                      21
 64          HC      2
 65          KK  EXMAIN
 66          KO      5                              21
 67          KM  WATERSHED 1 - PRE-DEVELOPMENT
 68          BA      1
 69          LS          70.75
 70          UD      1
 71          KK   TO-WQ   DUMMY
 72          KM    FLOW TO WQ BASIN
 73          KO      5       5                      21
 74          DR   TO-WQ
 75          ZZ
1
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              SCHEMATIC DIAGRAM OF STREAM NETWORK
 INPUT
  LINE      (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

   NO.      (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

     7        MAIN
                 .
                 .
    41           .------->   TO-WQ
    38        THRU
                 .
                 .
    47           .------->  BYPASS
    44      LOFLOW
                 V
                 V
    50      OUTFLW
                 .
                 .
    61           .           .<-------  BYPASS
    58           .       RETURN
                 .           .
                 .           .
    62         SUM...........
                 .
                 .
    65           .       EXMAIN
                 .           .
                 .           .
    74           .           .           .<-------   TO-WQ
    71           .           .       TO-WQ

 (***) RUNOFF ALSO COMPUTED AT THIS LOCATION
1*****************************************
 *                                       *
 *   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *
 *       JUN 1998 AND FEB 2010           *
 *           VERSION 4.1R                *
 *        RGMHEC2000 WWW.HEC-1.COM       *
 *  RUN DATE   09MAY11  TIME  22:03:42   *
 *                                       *
 *****************************************

 ***************************************
 *                                     *
 *    U.S. ARMY CORPS OF ENGINEERS     *
 *    HYDROLOGIC ENGINEERING CENTER    *
 *          609 SECOND STREET          *
 *       DAVIS, CALIFORNIA 95616       *
 *           (916) 756-1104            *
 *                                     *
 ***************************************

                          RALPH G. MASTROMONACO, P.E., P.C. -  EXTENTION BASIN RESEARCH
                          CASE 4 - EXTENTION BASIN CONTROL SYSTEM - AFTER DEVELOPMENT

    3 IO         OUTPUT CONTROL VARIABLES
                       IPRNT          5  PRINT CONTROL
                       IPLOT          5  PLOT CONTROL
                       QSCAL          0.  HYDROGRAPH PLOT SCALE

      IT         HYDROGRAPH TIME DATA
                        NMIN         10  MINUTES IN COMPUTATION INTERVAL
                       IDATE      1    0  STARTING DATE
                       ITIME       0000  STARTING TIME
                          NQ       2000  NUMBER OF HYDROGRAPH ORDINATES
                      NDDATE     14    0  ENDING DATE
                      NDTIME       2110  ENDING TIME
                       ICENT         20  CENTURY MARK

                   COMPUTATION INTERVAL     .17 HOURS
                        TOTAL TIME BASE  333.17 HOURS

          ENGLISH UNITS
               DRAINAGE AREA         SQUARE MILES
               PRECIPITATION DEPTH   INCHES
               LENGTH, ELEVATION     FEET
               FLOW                  CUBIC FEET PER SECOND
               STORAGE VOLUME        ACRE-FEET
               SURFACE AREA          ACRES
               TEMPERATURE           DEGREES FAHRENHEIT

      JP         MULTI-PLAN OPTION
                       NPLAN          1  NUMBER OF PLANS

      JR         MULTI-RATIO OPTION
                     RATIOS OF PRECIPITATION
                       .46       .60       .69       .79       .88      1.00

1
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PEAK FLOW AND STAGE (END-OF-PERIOD) SUMMARY FOR MULTIPLE PLAN-RATIO ECONOMIC COMPUTATIONS
FLOWS IN CUBIC FEET PER SECOND, AREA IN SQUARE MILES
TIME TO PEAK IN HOURS

OPERATION	STATION	AREA	PLAN		RATIOS APPLIED TO PRECIPITATION					
					RATIO 1 .46	RATIO 2 .60	RATIO 3 .69	RATIO 4 .79	RATIO 5 .88	RATIO 6 1.00
HYDROGRAPH AT +	MAIN	1.000	1	FLOW	41.91	98.75	143.57	198.38	251.35	327.94
				TIME	13.33	13.17	13.17	13.17	13.00	13.00
DIVERSION TO +	TO-WQ	1.000	1	FLOW	41.91	95.64	108.21	118.66	139.28	147.67
				TIME	13.33	13.00	12.67	12.50	12.50	12.33
HYDROGRAPH AT +	THRU	1.000	1	FLOW	28.29	96.75	143.57	198.38	251.35	327.94
				TIME	14.33	13.33	13.17	13.17	13.00	13.00
DIVERSION TO +	BYPASS	1.000	1	FLOW	25.89	71.76	111.00	160.00	204.80	266.50
				TIME	14.33	13.33	13.17	13.17	13.00	13.00
HYDROGRAPH AT +	LOFLOW	1.000	1	FLOW	2.41	24.99	32.57	38.38	46.55	61.44
				TIME	14.33	13.33	13.17	13.17	13.00	13.00
ROUTED TO +	OUTFLW	1.000	1	FLOW	.24	4.88	12.35	19.46	24.86	32.63
				TIME	15.00	15.50	14.83	14.83	14.83	14.50
			** PEAK STAGES IN FEET **							
			1	STAGE	340.95	343.29	343.74	344.09	344.32	344.63
				TIME	15.17	15.50	14.83	14.83	14.83	14.50
HYDROGRAPH AT +	RETURN	.000	1	FLOW	25.89	71.76	111.00	160.00	204.80	266.50
				TIME	14.33	13.33	13.17	13.17	13.00	13.00
2 COMBINED AT +	SUM	1.000	1	FLOW	26.07	72.09	111.36	160.44	209.12	278.47
				TIME	14.33	13.33	13.17	13.17	13.17	13.17
HYDROGRAPH AT +	EXMAIN	1.000	1	FLOW	26.51	72.38	111.47	160.79	209.24	278.47
				TIME	13.33	13.17	13.17	13.17	13.17	13.17
HYDROGRAPH AT +	TO-WQ	.000	1	FLOW	41.91	95.64	108.21	118.66	139.28	147.67
				TIME	13.33	13.00	12.67	12.50	12.50	12.33

1 SUMMARY OF DAM OVERTOPPING/BREACH ANALYSIS FOR STATION OUTFLW
(PEAKS SHOWN ARE FOR INTERNAL TIME STEP USED DURING BREACH FORMATION)

PLAN 1		INITIAL VALUE	SPILLWAY CREST	TOP OF DAM
	ELEVATION	340.00	342.80	351.00
	STORAGE	.00	1.39	22.15
	OUTFLOW	.00	.41	304.84

RATIO OF PMF	MAXIMUM RESERVOIR W.S.ELEV	MAXIMUM DEPTH OVER DAM	MAXIMUM STORAGE AC-FT	MAXIMUM OUTFLOW CFS	DURATION OVER TOP HOURS	TIME OF MAX OUTFLOW HOURS	TIME OF FAILURE HOURS
.46	340.95	.00	.060	.24	.00	15.17	.00
.60	343.29	.00	2.106	4.88	.00	15.50	.00
.69	343.74	.00	2.919	12.35	.00	14.83	.00
.79	344.09	.00	3.643	19.46	.00	14.83	.00
.88	344.32	.00	4.158	24.86	.00	14.83	.00
1.00	344.63	.00	4.847	32.63	.00	14.50	.00

*** NORMAL END OF HEC-1 ***

End of Paper