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Reclamation Potential of Urban Stormwater Runoff in Iran

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Large volumes of potable water are imported into almost all urban areas of Iran at extremely high cost, while considerable volumes of urban stormwater are disposed of out of the cities and wasted, mostly into bodies of saltwater. In this paper, urban stormwater is examined as a potentially valuable and reclaimable resource. A model is introduced in which stormwater runoff is captured and stored behind a small dam of height H with an overflow weir of length L to waste excess flows. At the same time, the stormwater is diverted through a side weir of width W, to be conveyed to suitable recharge grounds for later reclamation and use. A particular watershed, in the arid and rapidly urbanizing city of Bandar Abbas in southern Iran, with 24 years of rainfall records, was chosen and used in the model. The rainfall from nine other arid, semiarid and wet regions were used as input to the same watershed. The results show that the amount of reclaimable water as a percent of total runoff is almost the same for all the regions. This study provides a relationship, which defines the reclaimable water as a function of W, L and H. The relationship may be used for planning urban stormwater reclamation projects. The normal parameters defining arid, semiarid and wet climate are not of significance in this relationship. The relationship, however, may be further refined if one incorporates the number of intense storms as an extra parameter.

INTRODUCTION

Urbanization increases the volume of stormwater, greatly amplifies its peak and modifies its quality. Although the concept of river flow detention and storage for water conservation and flood control is an old one, the use of ponds for detention of urban stormwater began to gain broad recognition only in the early 1970s. Nowadays, stormwater detention ponds are being used in many countries, e.g. the United States, Australia, Sweden, Canada, etc. [1].

The purpose of such detention ponds in urban areas has been the mitigation of urban floods downstream and reduction of pollution. Another important function of such ponds, especially in arid regions, is the conservation and reclamation of urban stormwater. A successful river flow diversion scheme for groundwater recharge and reclamation has been in operation in southern Iran since 1982 [2]. In this paper, the reclamation potential of urban stormwater, using detention ponds, is investigated. In contrast to the reclamation of urban stormwater, which has gained much attention only in recent years, the practice of rainwater catchments, i.e., the interception, diversion and storage of rainwater from roofs and other small surfaces is a very old practice.

At present, more than 100 million people employ rainwater catchments for water supply all over the world [3]. Rainwater catchment systems or simply cisterns used to be a common feature of numerous towns and villages in Iran. Fewkes [4] investigated a rainwater collector installed in a UK house for a period of one year which was used for WC flushing. He found that the percentage of WC flushing water conserved each month ranged from 4% for June to 100% for September and February. Hermann et al. [5] found that rainwater utilization from roof runoff water directed into a storage tank could provide from 30-50% of total water consumption of a residence. A research on storm runoff retention technology commenced in Adelaide, Australia in 1987 studied the recharge of leaky wells and gravel-filled trenches by stormwater. Regarding this, Bekele and Argue [6], by using site inspection, showed that even in light clayey soil at least 80% of domestic roof runoff can be stored in the

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aquifers several meters below ground level and retrieved and utilized later. Nowadays, a substantial amount of research is being directed to better understand the issues involved in catchment systems. According to Heggen [3], these issues are: 1) The dilemma of "appropriateness"; 2) Technical developments and directions; 3) The contribution of system analysis.

In addition to several methods addressing the reuse of wastewater, stormwater and rainwater, Heaney, Wright and Sample [7] considered the early efforts by Thorenthwaite in climatology, in which, rainfall, temperature and the number of daylight hours in a day were combined to yield regional climatic projections and used water budget concepts to find out the potential volume of stormwater which can be reused for irrigation. The development of water reuse ponds aims at the reclamation and reuse of stormwater as a supplement to irrigable areas, such as golf courses, cemeteries, landscapes, community open spaces and turf areas. Designing such a pond may be based on how much stormwater is needed to assure a reliable irrigable water supply and how much stormwater actually leaves the pond. Wanielista and Yousef [8] simulated a water reuse pond in Florida using 15 years of daily rainfall, runoff, reuse and pond discharge data. They used water balance techniques that compute changes in incoming runoff, groundwater, direct rainfall to the pond, irrigation requirement, pond outflow, storage and evapotranspiration. Their model accurately simulated the actual performance of a monitored water reuse pond in Orlando, Florida, and constructed a series of rate-efficiency-volume curves, which are helpful in designing water reuse ponds. An analysis of the Florida curves suggests that water reuse ponds can provide a reliable source of irrigable water over the long term if a sizeable reuse volume is provided. They found that as much as 50% to 90% of the incoming runoff could be recycled back on the land, depending on the irrigation rate.

In this paper, a systematic analysis to determine the reclamation potential of urban stormwater using a detention pond and diversion facilities is investigated. The analysis is applied to an urbanized watershed located in the arid zone of southern Iran. The amount of urban stormwater runoff reclaimed is a function of rainfall (and resulting runoff), the size of the detention pond and diversion facilities. The resulting runoff from rainfall is based on a single event approach. To determine the effect of rainfall characteristics, such as average annual rainfall, average annual number of events, percent rainy days, average rainfall amount of each event, the actual rainfall records of other arid, semiarid and wet regions of Iran were imposed on the same urban watershed. General relationships between the percent reclamation of urban stormwater on the one hand and rainfall characteristics and size of detention and diversion facilities on the other hand are discussed. The procedure given in this paper could be used to determine the potential of urban stormwater runoff for the planning and preliminary design purposes of urban runoff reclamation.

DETENTION AND DIVERSION SCHEME

The basic elements of detention and diversion of stormwater are shown in Figure 1. Runoff is temporarily stored behind a small dam with height H, with an overflow weir of length L. At the same time, the water is diverted by gravity through outlet facilities, e.g., a rectangular weir with a width of W to recharge grounds or other uses. In this study, it is assumed that the bottom of the diversion weir is at the same elevation as the bottom of the pond. But this restriction may be easily removed. If topography does not permit gravity diversion, one could use pumpage of ponded water.

The governing equation for the detention and diversion scheme is:

$$Q_{\text{in}} - Q_{\text{div}} - Q_W = \frac{dS}{dt},$$

or:

$$\int Q_{\text{in}} dt = \int Q_{\text{div}} dt + \int Q_W dt + \int dS, \tag{1}$$

where:

- Q_{in} net inflow rate, i.e., runoff minus evaporation and infiltration,
- Q_{div} outflow rate by diversion for reclamation and reuse,
- Q_W wasted outflow rate over the dam,
- S volume of water in storage behind the dam,
- t time,

$S = 0$ at $t = 0$ and $S = 0$ at $t =$ end of runoff.

Calculation of the components of Equation 1 is carried out by application of the rainfall-runoff model as discussed later in this paper.

Normally, the rain and consequent runoff are of a short period and the pond stays dry after each

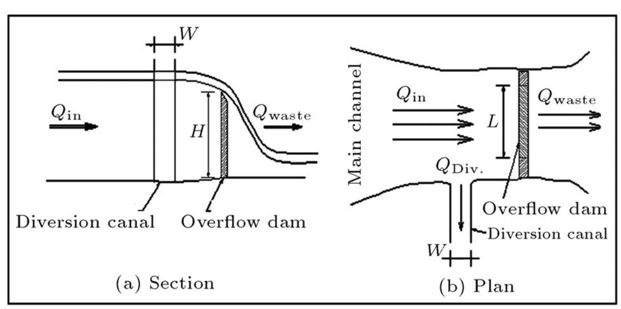

Figure 1. The concept of runoff detention and diversion scheme.

rainfall-runoff event. Short runoff, diversion and detention times cause negligible evaporation from the pond surface. For any effective overland flow, the reclaimed portion is a function of H, L and W. By assigning different values to H, L and W, the percent of reclaimed overland flow is obtained. The effective overland flow can be calculated by modeling the watershed with a specific rainfall by a suitable model. In this paper, the HEC-1 model was used

URBAN WATERSHED CHARACTERISTICS

Urban watershed characteristics have pronounced effects on runoff.

The city of Bander Abbas, which is located in the southern part of Iran along the north coastline of the Persian Gulf near the Hormoz Strait, consists of several parallel drainage basins, which discharge stormwater into the Persian Gulf.

The selected urban watershed includes three sub-basins; namely, B1, B2 and B3, as shown in Figure 2.

The latest version of a 1/25000 scale topographic map of Bandar Abbas was used to obtain the essential characteristics of these sub-basins that are shown in Table 1.

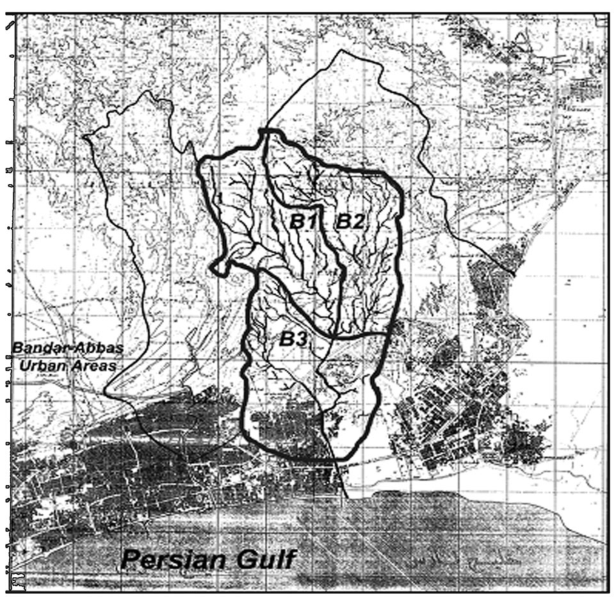

Figure 2. Plan of urban watershed considered.

The percent urbanization of each sub-basin in 1994 is calculated by dividing the residential area obtained from the 1994 maps to the total area. All potential areas for residential use are considered as the maximum urbanization possible in the future. The time of concentration of sub-basins B1, B2 and B3 were calculated using a kinematic wave formula [9] for full urbanization.

Considering topography and Figure 2, 40 percent of sub-basins B1 and B2 and 80 percent of sub-basin B3 are potentially prone to urbanization. Curve number values in Table 1 are estimates based on Soil Conservation Service guidelines and the soil characteristics of the considered watershed [10].

STUDY AREA RAINFALL CHARACTERISTICS

The rainfall data were provided by the Iranian Meteorological Organization and Iranian Water Resources Research Organization; the two major climatologic and hydrologic data sources. All hydrologic data for the Bandar Abbas study were obtained from the Bandar Abbas Meteorological Synoptic Station. This station is equipped with both non-recording and recording rain gages. Ten years of the 10-min interval rainfall data of each event (1969 to 1980) and 14 years of the daily rainfall data (1983 to 1996) are the only available data which were put at the disposal of the authors. Figure 3 shows the amount of 10-min interval rainfall data of Bandar Abbas for 10 years. In Figure 4, the

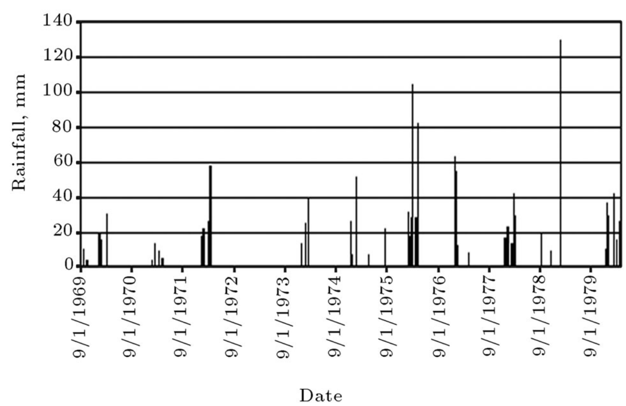

Figure 3. Amount of 10-min interval rainfall data of Bandar Abbas (1969-1980).

Table 1. Essential characteristics of selected watershed.

Sub basin	Area, km^2	Main Channel Length, km	Main Channel Slope, %	Urban Area in 1994, %	Max Urban Area, %	Time of Concentration, min	Curve Number
B1	6.0	5.6	1.8	10%	40%	150	86
B2	6.8	6.8	1.4	10%	40%	170	87
B3	9.8	4.3	0.35	60%	80%	240	90

daily rainfall of Bandar Abbas for 14 years is shown. These data are used in the proposed model after disaggregating into 1-hr data, using the appropriate distribution pattern discussed later in this paper.

A summary of pertinent Bandar Abbas rainfall characteristics is given in Table 2, which shows average annual rainfall, average number of effective events per year and percent rainy days. It also shows that in the 24 years of data there have been 129 effective rainfall events ($\geq$ 6 mm) and, on average, each event has 31.5 mm rain. The average intensity of the top 5% of the most intense events for Bandar Abbas is 153.7 mm/day. The parameters in Table 2 have been used to determine their significance, if any, in the model.

The average intensity of each effective rainfall event was calculated by dividing the amount of rain of the event by its duration. The derived intensity of 5% of the most intense events is used to obtain the data tabulated in the last two columns of Table 2. These data may be used to show the variability of percent reclaimable volume of different regions stormwater.

Figure 5 shows no particular pattern for rainfall distribution. In order to determine an appropriate rainfall distribution type, the actual 10-min interval rainfall data were fed into the model and the actual amount of reclaimable runoff was determined. Then, each rainfall event was assumed to have various distribution, such as Types I, IA, II and III of SCS and uniform distribution. It was found in Figure 6 that Type I of SCS gives the closest fit, as far as the amount of reclaimable runoff is concerned, while uniform distribution overestimates it by about 15 percent and Type III underestimates by about 7 percent.

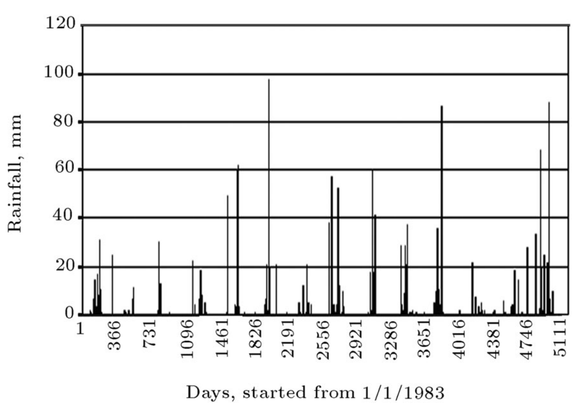

Figure 4. Daily rainfall data of Bandar Abbas (1983-1996).

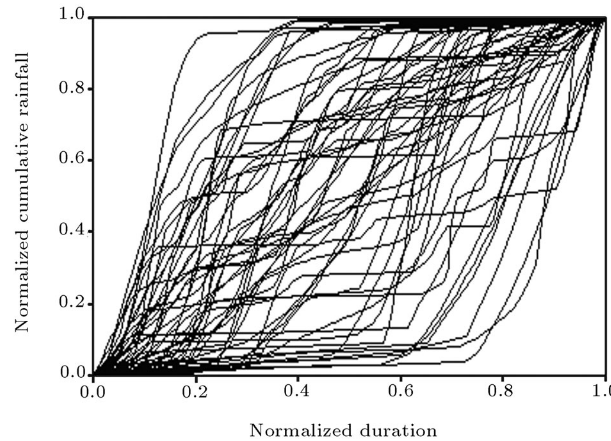

Figure 5. Actual rainfall distribution of 10-min rainfall data of Bandar Abbas (1969-1980).

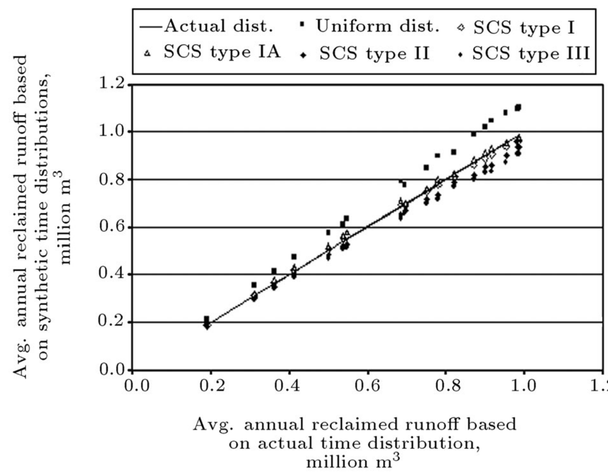

Figure 6. Appropriate rainfall time distribution type.

DERIVATION OF RUNOFF DIVERSION RELATIONSHIP

It is necessary to use a complete flow hydrograph over a period of years for water use studies [9]. All available rainfall data were used as the input to the rainfall-

Table 2. A summary of Bandar Abbas rainfall characteristics.

Average Annual Rainfall, mm	Total Number of Effective Events	Total Years of Data, yr	Number of Effective Events per Year	Percent Rainy Days, %	Average Rainfall in Each Effective Event, mm	Ave. Intensity of the Top 5% of Most Intense Events, mm/hr	S.D. of the Top 5% of Most Intense Events, mm/hr
179.7	129	24	5.4	1.8	31.5	6.4	1.7

runoff model. The reservoir component and diversion component are required to estimate the reclaimed fraction of overland flow. The chosen model must have the capability to handle these components. Among many rainfall-runoff models, such as SWMM, TR20 and HEC-1, the HEC-1 model could easily handle all above components. The HEC-1 model is designed to simulate the surface runoff resulting from precipitation, by representing the basin as an interconnected system of hydrologic and hydraulic components [11]. Each component models an aspect of the rainfall-runoff process within a portion of the basin. Surface runoff and stream channel components are required in almost all hydrologic problems. Reservoir and diversion components are the additional components required in this study. In the HEC-1 model, like the other lumped models, hydrologic processes can be represented by model parameters, which reflect the temporal, as well as the spatial average condition within a sub area. The limitations of this single event based model, which uses hydrologic routing instead of full St. Venant equations, are not significant in this study.

The prepared input data file for this study includes precipitation data, basin data, loss rate data function, unit hydrograph data, river and reservoir routing data and diversion data blocks. A schematic diagram of the considered watershed is shown in Figure 7.

The diversion facilities, including diversion canal and overflow dam, are located at the outlet of sub-basin B3. The HEC-1 model calculates the surface runoff hydrograph of the sub-basins B1 and B2, combines the two hydrographs, and routes the combined hydrograph through a stream channel in the sub-basin, B3. It computes the surface runoff hydrograph of sub-basin B3 and combines it with the routed hydrograph. Then, it splits the resulting hydrograph through the diversion canal and main channel, using pertinent hydraulic and routing principals.

The actual time distributed rainfall data are available and, therefore, an incremental precipitation time series of rainfall data were used. The SCS Curve Number method was used to estimate the precipitation losses, due to land surface interception, depression storage and infiltration. The SCS dimensionless unit hydrograph was used to transform the excess rainfall to overland flow. The Muskingum-Cunge routing technique was selected for the hydraulic river routing of hydrographs in the stream channel. The Level-Pool reservoir routing method, using the relationship between reservoir storage volume and elevation, was used for reservoir routing of the hydrographs.

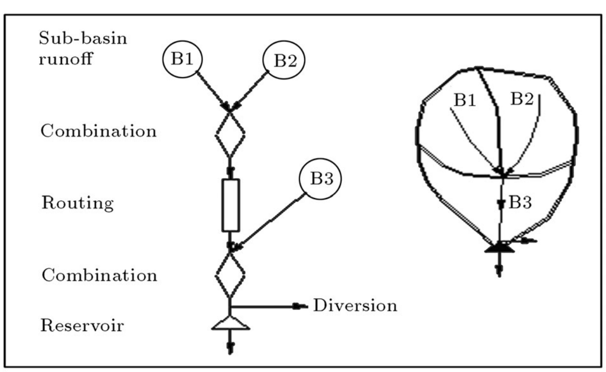

Figure 7. Schematic diagram of selected watershed and components of HEC-1 analysis.

In order to determine the reclaimed fraction of runoff for a basin area, CN, lag time, slope, roughness, geometry of main channel and floodplain and the geometry of reservoir were treated as constants while rainfall, height and length of the overflow weir of the dam, width of the diversion canal and the inflow rate and the resulting diverted flow rate, were changed for each run. In each run, the HEC-1 model simulates the hydrologic system of sub-basin B1, B2 and B3 with the specified diversion facilities, rainfall data, etc. Remember that in Equation 1, the left hand term (i.e., $\int Q_{\text{in}}dt$) is the integral of the resulting hydrograph at the exit of sub-basin B3, just before the diversion facilities. The diversion block of HEC-1 input file, which was defined based on the hydraulic relationship between the height and length of the overflow weir of the dam and the width of the diversion canal, forced HEC-1 to separate the diverted part of the stormwater from the input hydrograph. The first term of the right hand side of Equation 1 (i.e., $\int Q_{\text{div}}dt$) is the integral of diverted flow. The stored volume of stormwater was obtained by routing the remainder flow through the reservoir, which is the 2nd term of the right hand side of Equation 1 (i.e., $\int dS$). Finally, the integration of the overflow hydrograph of the dam is the last term of Equation 1 (i.e., $\int Q_W dt$). To find out the reclaimed volume of total runoff, using all the available rainfall data, a Matlab-based computer package, including a main program and 3 sub-programs that coupled with the HEC-1 model, was developed.

RESULTS AND DISCUSSION

Reclaimed Stormwater Volume of Bandar-Abbas

Applying the above procedure to the Bandar Abbas watershed, using ten years of 10-min actual data and 14 years of disaggregated daily data, resulted in relationships between percent and average annual volume of reclaimed runoff versus height of dam (H), length of overflow weir of dam (L) and width of diversion canal (W). The results are shown in Figures 8 and 9.

For 129 rain events, 4 values for the width of the diversion canal, 10 values for the height of the dam and 4 values for the length of the overflow weir of the dam, it is necessary to run HEC-1 about 20640 times.

The basic purpose of this investigation was to obtain a mathematical relationship between the above variables, primarily for planning purposes. The effect of H, W and L is clearly shown in Figures 8 and 9 for Bandar Abbas, as well as in Figures 10 to 12 for the other nine cities. Larger values of H and W clearly allow most of the runoff to be diverted and reclaimed i.e., the effect of L is negligible. The rate of change of reclaimable runoff as a function of W, H and L is more pronounced for smaller W and H and, as H and W increase, the reclaimable runoff also increases, while, for smaller H and W, the reclaimable runoff decreases with increasing L. All these factors were taken into account for deriving and choosing the next proposed formula. From a total of 16 curves fitted to a total of

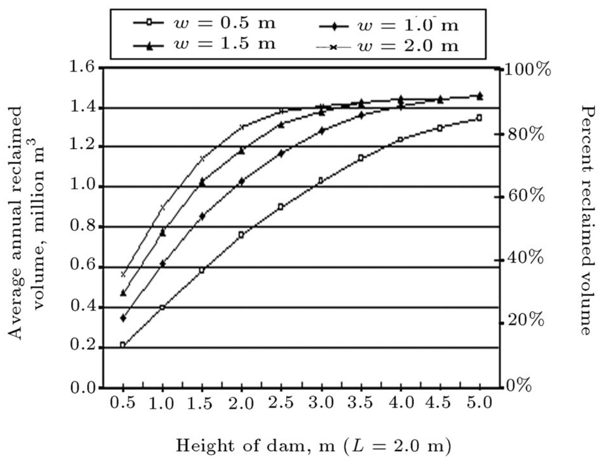

Figure 8. Runoff reclamation for Bandar Abbas ($L = 20$ m).

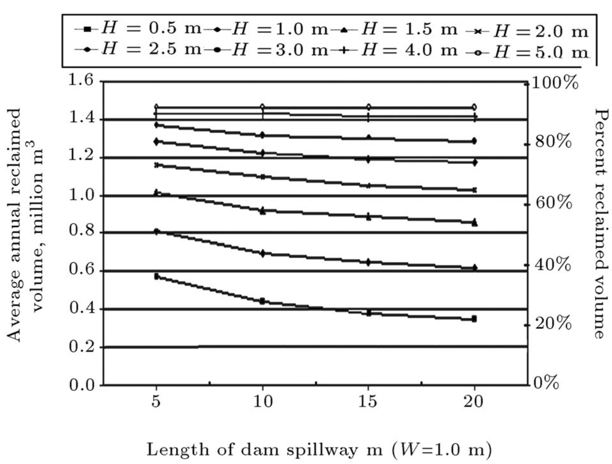

Figure 9. Runoff reclamation for Bandar Abbas ($W = 1.0$ m).

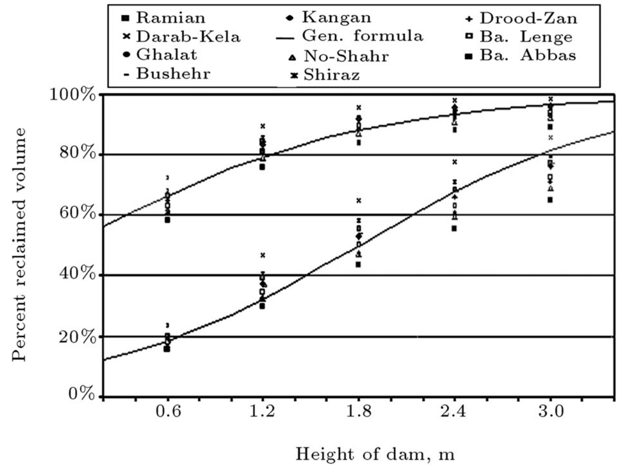

Figure 10. Generalized runoff reclamation. Upper curves: $W = 2.0$ m, $L = 5.0$ m; and lower curves: $W = 0.5$ m, $L = 20.0$ m.

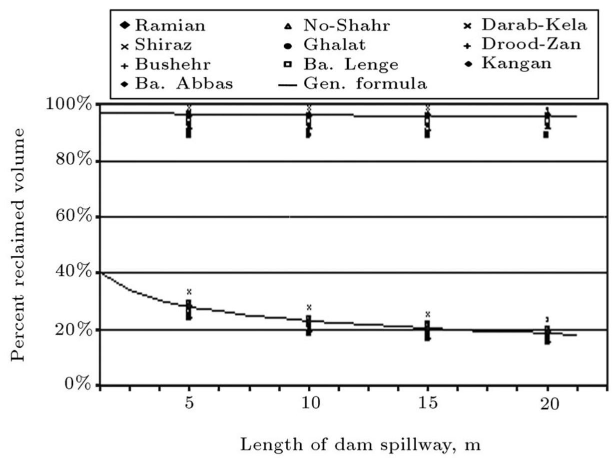

Figure 11. Generalized runoff reclamation. Upper curves: $W = 2.0$ m, $H = 3.0$ m; and lower curves: $W = 0.5$ m, $H = 0.6$ m.

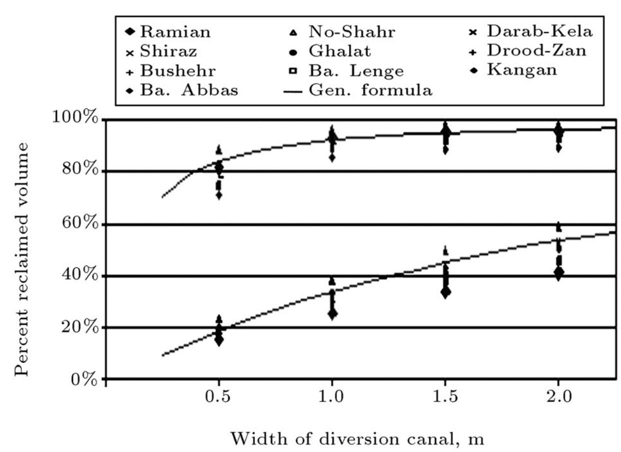

Figure 12. Generalized runoff reclamation. Upper curves: $H = 3.0$ m, $L = 5.0$ m; and lower curves: $H = 0.6$ m, $L = 20.0$ m.

160 points, some of which are shown in Figures 7 and 8, the relationship that fits the data reasonably well is the following.

$$V_{\text{div}} = \frac{V_{\text{tot}}}{1 + A\frac{L^{B-CH}}{W^D}e^{-EH}}. \tag{2}$$

In which A, B, C, D and E are constant parameters to be determined and:

V_{tot} total runoff volume of stormwater, m^3,
V_{div} diverted (reclaimed) volume of stormwater, m^3,
L length of overflow weir of dam, m,
H height of dam, m,
W width of diversion canal, m.

Non-linear least square analysis was performed with parameters $A = 1.0124, B = 0.45, C = 0.09, D = 1.04$ and $E = 0.6365$. The data used fits the proposed equation with a correlation coefficient $R^2 = 0.966$.

It is seen that for the 22.6 km^2 urban watershed in Bandar Abbas, it is possible to reclaim up to 1400000 m^3 water per year, using a dam 4.0 m high, a diversion canal 1.0 m wide and an overflow weir 20.0 m long.

The proposed relationship is applicable for H larger than 0.5 meters. In fact, a diversion scheme normally requires a minimum height for the diversion dam, in order to be able to divert low flows. The effect of each variable H, W and L is easily determined from Equation 2.

Simulation Using Other Rainfall Data

To obtain the relationship between climatologic characteristics and the reclaimed fraction of runoff volume, daily rainfall data of nine other stations were disaggregated and applied to the Bandar Abbas watershed as input rainfall data. These stations belong to various climatologic regions. Type I of SCS was used for disaggregating these daily rainfalls. These stations are No-Shahr, Ramian and Darab-Kala, which are located south of the Caspian Sea, belonging to a wet climate; Shiraz, Ghalat and Dorood-Zan, which are located in the Fars province, with a semi-arid climate and Bushehr, Bandar-Lenge and Kangan, as well as Bandar Abbas, which are along the arid coast of the Persian Gulf. Table 3 shows the rainfall characteristics of these nine stations in addition to Bandar Abbas.

The average annual rainfall is more than three quarters of a meter per year for the first three cities. The last three cities, plus Bandar Abbas, all have average rainfalls less than a quarter of a meter.

The same model and procedure described for Bandar Abbas was used to predict the storm runoff reclamation potential of these nine cities. Using rainfall data for each city by varying the detention and diversion facilities, i.e. varying H, W and L, the same watershed was used as before. Parameters A, B, C, D and E in Equation 2 were determined as shown in Table 4. Percent reclaimable water i.e. the ratio of V_{div} and V_{tot} for all cities is plotted in Figures 10 to 12 for selected values of the sizes of

Table 3. Rainfall characteristics for nine other stations.

Station	Average Annual Rainfall, mm	Total Number of Effective Events	Total Years of Data, yr	Number of Effective Events per Year	Percent Rainy Days, %	Average Rainfall in Each Effective Event, mm/day	Ave. Intensity of the Top 5% of Most Intense Events, mm/hr	S.D. of the Top 5% of Most Intense Events, mm/hr
No-Shahr	1105.8	905	30	30.2	13.6	35.1	3.5	1.0
Ramian	857.0	666	23	28.9	12.0	27.7	2.6	0.9
Darab-Kala	753.7	774	28	27.6	10.6	25.3	2.2	0.5
Ghalat	570.5	408	27	15.1	6.6	36.7	2.4	0.4
Dorood-Zan	467.5	126	9	14.0	6.4	33.2	1.8	0.2
Shiraz	372.8	380	30	12.8	5.1	28.1	2.1	0.6
Bushehr	242.0	217	31	7.0	2.4	28.9	2.8	1.3
Kangan	199.0	124	19	6.5	2.2	28.1	2.4	1.7
Bandar Lenge	162.1	127	29	4.4	1.6	32.6	2.7	0.5
Bandar Abbas	179.7	129	24	5.4	1.8	31.5	6.4	1.7

Table 4. Values of parameters A, B, C, D and E and correlation coefficient (R^2).

Station	A	B	C	D	E	R^2
No-Shahr	1.077	0.467	0.103	1.143	0.807	0.983
Ramian	1.041	0.438	0.095	1.185	0.984	0.983
Darab-Kala	1.007	0.420	0.094	1.244	1.221	0.985
Ghalat	1.135	0.477	0.109	1.203	0.870	0.982
Dorood-Zan	1.109	0.459	0.107	1.247	1.004	0.982
Shiraz	0.997	0.444	0.105	1.18	0.988	0.981
Bushehr	1.068	0.450	0.099	1.188	0.994	0.984
Kangan	1.111	0.449	0.095	1.216	1.000	0.984
Bandar Lenge	1.091	0.462	0.102	1.180	0.897	0.983
Bandar Abbas	1.012	0.451	0.090	1.040	0.636	0.966

detention and diversion facilities. The plotted percent reclamation for all cities shows not only the same trend, but also, they are, contrary to expectation, very close together. The normal characteristics of wet, semiarid and arid climates are of no significance in the percent of reclamation water, a fact which is discussed later in this section.

Contrary to the results obtained in the model, one would have expected that rainfall characteristics do have a significant effect on the percentage of runoff which could be reclaimed. The percent of runoff reclaimable shows only a very small variation for different locations. This is seen both from Figures 10 to 12 and from the parameters A, B, C, D and E, as calculated in Table 4.

The data from all the cities were used to obtain a general formula for runoff reclamation potential. This general formula is Equation 2 with $A = 1.0633, B = 0.45, C = 0.0995, D = 1.1756$ and $E = 0.9446$ with $R^2 = 0.9446$, which is plotted as a solid line in Figures 10 to 12. For example, for $W = 1.0$ m, $H = 1.8$ m and $L = 10.0$ m, the percentages of total runoff which can be reclaimed are $68.9, 76.4, 84.1, 70.6, 76.4, 78.6, 76.2, 75.0, 72.1$ and 64.7, respectively, for No-Shahr, Ramian, Darab-Kala, Ghalat, Doroud-Zan, Shiraz, Boushehr, Kangan, Bandar Lenge and Bandar Abbas. The general formula results in 73.0 percent. Therefore, one could use the proposed general formula as a guide for urban stormwater reclamation projects in the planning or preliminary design stages.

None of the rainfall characteristics as shown in Table 3 had any significant effect on the percentage of reclaimable runoff. In order to refine the proposed formula further, other less common characteristics of rainfall were investigated. One such characteristic is the average intensity, mm/hr, of the top 5% intense rainfall for each city. The result obtained is shown in Figure 13.

Figure 13 shows that the more intense the storms, the less the percentage of reclaimable runoff. This is to be expected, since, in less intense storms, most of the runoff is captured behind the dam and is gradually diverted for reclamation. In intense storms, large flows are produced and relatively more of it is wasted over the dam. This effect is not incorporated into the general formula because, normally, the data for the top 5% of intense storms are not readily available.

Water Diversion Policy

The purpose herein attained was to develop generalizations on the conservation i.e., reclamation potential of urban runoff in Iran. The general formulation attained is given by Equation 2 with $A = 1.0633, B = 0.45$, $C = 0.0995, D = 1.1756$ and $E = 0.9446$. This formula relates the size of diversion facilities and

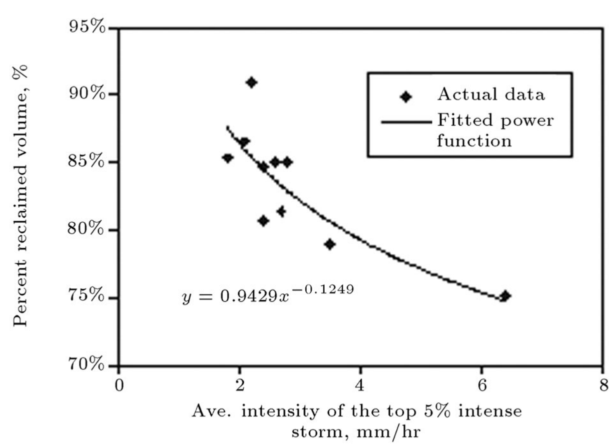

Figure 13. The effect of intense storms on urban stormwater reclamation potential.

the percent of total runoff which potentially can be diverted.

The finding of this investigation may be used in determining any suitable water diversion management policy. Obviously, the criteria of how much water should be diverted depends on the supply and demand of water in the region. It has not been the intent of this paper to investigate the demand and the real value of water in this region. The supply part has been investigated in this paper. For example, for the Bandar-Abbas urban region, with a 22.6 km^2 area, the maximum runoff which can be diverted is, on the average, 1585000 m^3/yr. The relationship between average annual maximum reclaimed volume of stormwater runoff and average annual precipitation for all the cities studied is shown in Figure 14.

In the cities where piped water is available, heavy subsidies are in place and each cubic meter of water is priced at about 210 rials (equivalent to 0.025 US dollars at the current official exchange rate of 8400 rials to a dollar). While in the cities where water is brackish, the consumers are willing to pay tanker transported sweet water at a rate of 50 times as much.

A cost analysis of the size of diversion facilities versus the amount of urban water to be reclaimed is required to determine a cost efficient scheme for urban stormwater diversion. Pilot field studies are also desirable to verify or modify formula 2.

CONCLUSIONS AND RECOMMENDATIONS

The major conclusions of this investigation, conducted to evaluate the reclamation potential of urban stormwater runoff in Iran, are summarized:

1) Bandar-Abbas rainfall distribution for the 24-year data is adequately described by Type I SCS distribution and is an effective means for use in runoff conservation and reclamation studies;

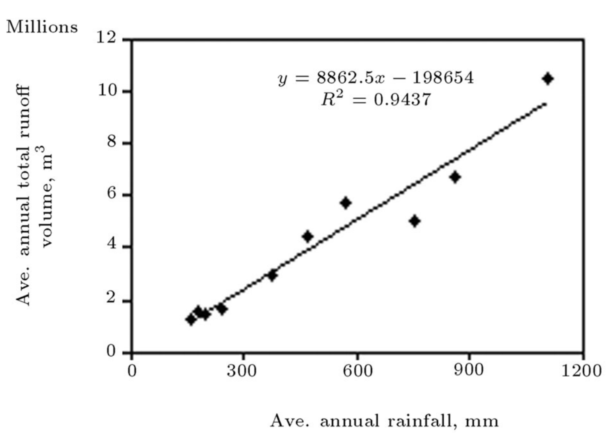

Figure 14. Average annual total runoff versus average annual rainfall of 10 studied cities.

2) While even the most extensive monitoring programs can only provide reclamation potential information at a few locations, the applied model discussed in this paper provides valuable reclamation potential information at many locations. This paper presents and compares the various sizes of water diversion facilities which may be used in water diversion planning and management;
3) The relationship between percent reclaimable runoff on the one hand and size of diversion facility on the other, is essentially the same for different locations in the country with different rainfall patterns;
4) The proposed relationship could be used as a guide in planning urban stormwater runoff reclamation projects;
5) Urban runoff water is potentially a very attractive source and it becomes more so when the results of this study are coupled with proposed field pilot studies and cost analysis;
6) Clearly, the attractiveness of urban water runoff reclamation, as investigated in this paper, should be weighed on its merit and evaluated against other potential sources such as salt-water conversion;
7) The various factors of urban stormwater reclamation discussed here will help policy makers and urban water authorities to pay more attention to this type of water conservation with increasing frequency;
8) Urban stormwater reclamation plays a major role in water conservation and groundwater recharge in arid parts of Iran and other water shortage regions where there is insufficient or no irrigation water.

The following recommendations are made to better understand the potential of urban stormwater runoff conservation in Iran:

1. The reclamation possibilities of urban stormwater runoff were investigated for a particular urban watershed. It is recommended to apply it to other watersheds and to incorporate other parameters such as watershed area, slope, number of detention ponds in a watershed and non-gravity transfer of water e.g. pumps;
2. It is highly recommended to compare the findings of this study with a pilot field investigation;
3. In addition to the quantitative aspects, which are the subject of this paper, it is highly recommended to study qualitative aspects of urban stormwater runoff;
4. For optimization purposes, cost analysis and related economic studies are very important.

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