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WATER SECTOR GOVERNANCE: ROBUST WATERSHED HYDROLOGY MODELLING OPTIONS FOR PARTICIPATIVE GOVERNANCE

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Choosing a model for watershed hydrology is not a simple task. Indeed, entering that labyrinth of literature is somewhat like entering a dense jungle. At the academic level there are literally hundreds of models which have been suggested to model watershed hydrology. If we take into account models that aim at specific components of the water cycle the number is likely to be even higher. A recent review of mathematical modelling of watershed hydrology carried out as a 150th Anniversary Paper for the American Society of Civil Engineers lists a sample of sixty models and carries a list of over 350 references. As an academic exercise it is possible to spend a few years simply reviewing and comparing mathematical modelling of watershed hydrology. For this reason, it is important to put forward the context of the watershed modelling exercise we are about to undertake and be clear about the purpose and the assumptions under which the following models are being suggested.

The first important point is that we are looking at these models as instruments of participative governance in the water sector. Participative governance in the water sector implies a common agreement on assessment of the resource and a discussion of how that resource is going to be utilized by different stakeholders. This is a process that is bounded in time. We need here methods that allow for participation, are readily understood in principle and are robust, that is, they can give reasonable estimates rapidly on the basis of existing data and will allow us to explore different scenarios and their implications albeit on the basis of some further exploration and information. The problem here is how to walk the tight rope. Most participative methods lack reasonably validated quantification; while they are good for qualitative trends and information and are transparent, quantification is poor. In contrast, scientific methods claim high precision in quantification, but are time consuming, require far more data than is generally available and are opaque.

One of the best examples of this is watershed development, an example of an intervention that is simultaneously bio-physical as well as socio-economic. Our review of watershed experience indicates that though there are several reports and evaluations about different watershed projects and programmes, there is very little reasonably accurate data or good estimates of what changes watershed development has brought about in the hydrology of particular watersheds and, equally importantly, in the hydrology of the sub-basins and basins that they fall in. Similarly, watershed development planning has rarely included a reasonably good

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assessment of potential changes in hydrology and water availability and used it as a basis for planning and monitoring of watershed development projects. One reason for this state of affairs has been that there is very little awareness of the need for a minimum bio-physical bench marking and as a result it becomes impossible to evaluate the bio-physical impact of watershed development. This becomes important in view of the conflicting and controversial claims that are being made about the spread of watershed development. While watershed development proponents have generally argued that watershed development increases water availability in the sub-basin and improves and stabilizes flow regimes, there have also been claims that watershed development results in decrease in downstream water availability and also that some of the extra watershed treatment work has little or no effect on water regimes downstream. Under such circumstances anyone who wants to seriously evaluate the potential of watershed treatment or that of small water harvesting structures or land treatment has to turn to modelling as a possible option.

However, the approach to choosing a modelling procedure here will differ from an academic exercise in several ways. One of the constraints is that the model to be chosen must be robust enough to take account of the constraints under which such an exercise will have to take place. One of the constraints is the nature of the data that can become available routinely from a watershed project. Another is the level of sophistication or lack of it of secondary data that can be routinely made available for the watershed and the cost of obtaining very sophisticated data. Another constraint similarly is the technical expertise in computation, mathematical modelling, simulation, GIS/RS techniques and such like. Thus the model has to be adaptable to primary and secondary data constraints and has to be as far as possible free from too complex mathematical computation and specialization. At the same time it must have the potential of refining its estimates if better data or computational and analytical tools become available.

It is with this framework that we have approached the matter of making an initial choice of possible modelling options. For this purpose we have assumed that the following data may be available, but it will be difficult to get more sophisticated data. Thus the model must be capable of giving reasonable results with this data set.

Meteorological data:

- rainfall data only for the nearest taluka place – if we are fortunate we may have an IMD station nearer to or at the same distance as the taluka place – and will most likely be in the form of daily rainfall figures at best
- similar figures for pan evaporation on a daily or monthly basis from the nearest observation station

Data for the watershed/sub-basin:

- broad slope classification,
- broad soil type classification and
- cover and cropping pattern.

At the same time more refined data collected at the village level should subsequently be able to help us refine our estimates.

We have also assumed that we do not readily have flow data at the watershed exit point, though we may have data at the sub-basin level where we may choose a strategically located tank or dam that maintains flow data. This implies that we cannot use many of the models, especially those that postulate watershed parameters that require to be calibrated through watershed flow monitoring, Similarly, we should emphasize that many of the models are aimed at determining peak run offs and at modelling storm flows and hydrographs. It should be made clear that the modelling exercise here is not aimed at peak flows and therefore dispenses with time of concentration and other variables which are specifically related to storm processes through time. In that sense, even though the suggested models borrow from runoff models that are used in peak flow estimation, they do so only in order to assess water yield rather than its variation over typical storm durations.

An analysis of the ASCE review mentioned above shows that the basic theoretical models have been laid down in the 1960s and 70s and the later developments have mainly been computational and technical improvements and adaptation to later techniques like GIS/RS techniques, computer processing and finite element and dispersed modelling, etc. These basic models are more amenable to the constraints that we have to work under. We have therefore relied on the time tested basic models that have been shown to work reasonably well. We have relied for this purpose on Tideman[1] and on our own earlier work based on Datye's modified models[2]. Datye's models have been used in the Udaipur's Jaisamand catchment/sub-basin study as well as in the Sabarmati study. Both reports show the value of the modelling exercise which goes much beyond simple determination of water balance components. They form essential elements in exploring how far local resources will go, what is the degree of assurance that they can provide, what are the components of variable and assured water resources available, what supplemnts will be neded from the larger system, etc. The model thus becomes the instrument for tackling most allocation issues at the heart of water governance. However, the significance of these issues cannot be highlighted unless the model is seen to operate within a normative framework that is compatible with principles of sustainable/regenerative use and equitable access and participatory/deliberative democracy. Issues related to the normative framework are not tackled in this note.

SCS Based Runoff Model for Indian Conditions

The Soil Conservation Services (SCS) of the US have developed a model[3] that is quite popular because of its simplicity and reasonable accuracy given its low data needs. Tideman suggests a model adapted to Indian conditions through an adaptation of its parameters. This model works on non-recording rain gauge data, and typically uses 24 hour rainfall figures, though it can be adapted to monthly rainfall figures as well. It mostly employs rainfall and watershed data that are or can be relatively easily available.

The principle behind the SCS model is simple enough. It simply assumes that the proportion of actual retention of rainfall and the potential maximum retention is equal to the proportion of direct runoff and the rainfall less initial abstraction. This leads to a relationship as follows:

$$Q = (R - Ia)^2 / [(R - Ia) + S]$$

where Q = actual runoff
R = rainfall
S = Potential maximum retention or storage
Ia = Initial abstraction during the period between the beginning of rainfall and beginning of runoff

All values expressed in mm

SCS had suggested the following relationship between Ia and S, namely, Ia = 0.2S. However, Tideman suggests the following relationship between Ia and S according to the Antecedent Meteorological Conditions (AMC) in Indian conditions.

Black soils region [AMC II and III)	Ia = 0.1S
Black soils region [AMC I]	Ia = 0.3S
All other regions	Ia = 0.3S

Table 1: Relation of Ia and S for Indian conditions

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[1] Tideman (1998)
[2] SOPPECOM and VIKSAT (2003) and Paranjape et al (2001)
[3] Singh (1989) pp. 185-189.

Antecedent Moisture Conditions (AMC) are classified by hydrologists as given below.

Antecedent moisture condition	5-days total antecedent rainfall (mm)		Runoff producing condition
	Dormant season	Growing season	
I	< 12.7	< 35.6	Lowest runoff potential
II	12.7 to 27.9	35.6 to 53.3	Moderate runoff potential
III	> 27.9	> 53.	Highest runoff potential

Table 2: Antecedent Moisture Condition

The values for S are related to a parameter termed the Curve Number (CN) as follows:

$$CN = 25400 / (254 + S)$$

Where: CN = Curve number
S = maximum retention or storage in mm depth.

Conversely,

$$S = 254\,(100 - CN) / CN$$

The Curve Number is tabulated for different land use and hydrologic soil group as follows.

Land use/ cover	Treatment/ practice	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row	Poor	77	86	91	94
Row crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	61	73	81	84
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close seeded	Straight row	Poor	66	72	85	89
	Straight row	Good	58	72	84	85
Legumes or rotation	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
Meadow	Contoured and terraced	Poor	63	73	80	83

	Contoured and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woodlands (farm wood lots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads			59	74	82	86
Roads (dirt)			72	82	87	89
Roads (hard surface			74	84	90	92

Table 3: Runoff Curve Numbers for hydrologic and soil cover complexes [4] (AMC II and Ia = 0.2 S)

Reported CN values for AMC II may be corrected for AMC I and III according to the following chart/graph.

The hydrologic soil groups A through D have been described by Tideman as follows.

Hydrologic Soil Groups [5]

Group A (Low runoff potential)

This group includes deep sands with very little silt and clay and deep, rapidly permeable loam with high infiltration/transmission rates. These soils have a rapid rate of water transmission (greater than 8 mm/hr).

Group B (Moderately low runoff potential)

This group includes sandy and loam soils less deep or with less aggregate and coarser soil fractions than Group A having a moderate infiltration rate when saturated. These soils have a rapid to moderate rate of water transmission (4 to 8 mm/hr).

Group C (Moderately high runoff potential)

This group consists of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils contain considerable clay and colloids, though less than those of Group D. These soils have low infiltration rates when thoroughly wetted and have a moderate rate of water transmission (1 to 4 mm/hr).The infiltration rate of the soils of this group and the group D can be extremely high in the initial part of rainfall due to the fairly wide and deep cracks characteristic to soils from these groups. Wetting the clays thoroughly, before testing should be an important consideration. The infiltration rates in unsaturated cracked clays can be higher by an order of magnitude, affecting greatly the results.

Group D (High runoff potential)

This group consists of chiefly clay soils with high swelling potential having very low infiltration rates when thoroughly wetted. Soils with a permanent high water table, soils with clay pan or near the surface and shallow soils over nearly impervious material fall under this group (very low infiltration rates, less than 1 mm/hr).

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[4] Tideman (1998) p. 93.

[5] Tideman (1998) pp. 89-90.

Soils from different groups as above can be easily classified in the field employing simple tools, for example, a piece of ply board, a kitchen knife, a glass, saucers and set of sieves will go a long way. Boys and girls from the village can master the testing methods with some guidance. Similarly, infiltration or water transmission rates of the soils can be measured in the field by employing simple tests. These testing methods are explained in the soil and water training notes written and compiled by V.N.Gore.

In case different areas of the watershed have different curve numbers, a weighted average of the curve number is used.

CN = [Sum of (Ai.Cni)]/A

where Ai is the ith area of the watershed with a curve number CNi and A is the total area of the watershed.

The Haan Model [6]

The Haan model is a four parameter model for water yield from small watersheds. It assumes that rainfall intensity and the moisture holding and transmission characteristics of the surface and subsurface soil layers are the most important characteristics controlling water yield from small watersheds.

The soil moisture zone is considered to be composed of two subzones, the upper and the lower zone. The upper zone is the zone with a moisture holding capacity of 25 mm. The moisture holding capacity of the lower zone is taken to be Mc. The difference between the two layers is that evapotranspiration takes place at the full potential rate from the upper zone but takes place at a lower rate depending on the moisture content of the lower zone. Additionally, on the day that rainfall occurs, it is reduced further by a factor of 2 to take into account cloud cover and low solar radiation. All evapotranspiration comes from the soil moisture.

Rainfall when it falls is partitioned into infiltration and surface runoff. Infiltration is equal to the rainfall when it is less than the maximum potential infiltration. Otherwise it takes place at maximum potential rate while both the upper and lower zones have not reached their moisture holding capacity. After both soil zones are filled to capacity, the infiltration rate falls to zero. Rainfall less infiltration gives us the surface runoff.

Deep seepage takes place at a rate that is proportional to the maximum possible seepage rate on a daily basis as well as on the extent of soil moisture in the lower zone.

Part of the deep seepage returns within the watershed as interflow or return flow and contributes to the run off or water yield from the watershed.

The model depends on four parameters: maximum infiltration rate, maximum deep seepage rate, moisture holding capacity of the lower zone and fraction of deep seepage returning as interflow.

Mathematically, the following equations will be applicable:

Infiltration

$$I = Im \text{ when } R >= Im \text{ and } Mu < 25 \text{ or } Ml < Mc$$

$$I = R \text{ when } R < Im \text{ and } Mu < 25 \text{ or } Ml < Mc$$

$$I = 0 \text{ when } Mu = 25 \text{ or } Ml = Mc$$

where I = Infiltration rate

Im = Maximum infiltration rate

R = Rainfall

Mu = Soil moisture in upper zone

Ml = Soil moisture in lower zone

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[6] Singh (1989) pp. 195-196.

Mc = Soil moisture capacity of lower zone

Evapotranspiration

$$Ea = Ep \text{ when } R <= 25 \text{ and } Mu <= 25$$

$$Ea = Ep(Ml/Mc) \text{ when } R <= 25 \text{ and } Mu = 0$$

$$Ea = 0.5Ep \text{ when } R > 25 \text{ and } Mu > 0$$

$$Ea = 0.5Ep(Ml/Mc) \text{ when } R > 25 \text{ and } Mu = 0$$

where Ea = actual evapotranspiration

Ep = potential evapotranspiration (as worked by one of the standard methods)

and the rest are as defined earlier.

Surface run off

$$Rus = R - I$$

where Rus is the the direct surface runoff

Deep seepage

$$Sd = Sm(Ml/Mc)$$

where Sd = deep seepage

Sm = maximum deep seepage

Return flow

$$Rur = alpha.Sd$$

where Rur = return flow contribution to run off

alpha = parameter controlling fraction of deep seepage that returns as run off.

Data Requirements

Strictly speaking, the model requires continuous rainfall monitoring data. However, the model has been developed keeping in view the availability of daily rainfall figures which may then be converted to a hypothetical hourly or even six-minute rainfall figures based on standard storm distributions such as those given in Tables 4 and 5. (These patterns pertain to specified US conditions and need to be replaced by relevant patterns in Indian conditions if they are to be used within India.) Maximum deep seepage and maximum infiltration rates for typical soils in the watershed may be assessed directly by standard methods. Alternatively, they may be assessed on the basis of soil texture classes, though this is recommended only when it is not possible to conduct actual infiltrations tests in selected locations in the watershed. Pertinent soil moisture zones will depend on type of cover and land use. In agricultural lands crop and land together would determine soil moisture zones. For perennial trees and shrubs the soil moisture zone may be deeper than it is for many seasonal crops. Determining evapotranspiration is discussed separately.

Hour	Accumulated fraction of daily rainfall	
	Type I storm	Type II storm
0-1	.017	.011
1-2	.035	.022
2-3	.055	.035
3-4	.076	.048
4-5	.091	.064

5-6	.125	.080
6-7	.156	.100
7-8	.194	.120
8-9	.254	.147
9-10	.515	.181
10-11	.624	.235
11-12	.682	.663
12-13	.727	.772
13-14	.767	.820
14-15	.798	.850
15-16	.830	.880
16-17	.854	.898
17-18	.870	.916
18-19	.902	.934
19-20	.926	.952
20-21	.944.964	
21-22	.963	.976
22-23	.981	.988
23-24	1.000	1.000
Based on Kent (1968)		

Table 4: Distribution of hourly rainfall within a day [7]

Minutes	% of rain within the interval	Cumulative %
0-6	4	4
6-12	6	10
12-18	9	19
18-24	33	52
24-30	18	70
30-36	9	79
36-42	7	86
42-48	6	92
48-54	4	96
54-60	4	100
Based on SCS (1975)		

Table 5: Rainfall distribution within an hour [8]

References suggest determining the four parameters through an optimization process. It is recommended that three years of observed monthly runoff values be taken for comparison of computed and actual runoff and the sum of squares of deviation be minimized.

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[7] Singh (1989) p. 196.

[8] Singh (1989), p. 196.

Datye Sabarmati Model

Datye has modified the Haan model and simplified it in some respects and enhanced it in some others in the model that was used in the SOPPECOM Jaisamand SWHS study[9] and later in the Sabarmati study[10]. The following description is based on the more refined model presented in the latter study.

Datye eliminates the two zones and treats a single root zone layer in its place. The root zone depth is dependent on the field crop and the field. He also takes note of the fact that not all moisture in the root zone is available for evapotranspiration. The additional operative parameter is the available moisture at a given time as well as the maximum available moisture capacity of the soil. The evapotranspiration equations change accordingly. He also uses the average infiltration rate instead of the maximum infiltration rate in the Haan model and allows infiltration at all times irrespective of soil moisture. Soil moisture augmentation is sequential, that is no deep seepage occurs till soil moisture reaches maximum capacity in the root zone. In some places he also takes account of initial abstraction.

The model then may be presented as follows:

Infiltration

$$I = Iav \text{ when } R >= Iav$$

$$I = R \text{ when } R < Iav$$

where I = Infiltration rate
Iav = Average infiltration rate
R = Rainfall

Evapotranspiration

$$Ea = [Ma/(1-p)Mca]Ep$$

where Ea = actual evapotranspiration

Ep = potential evapotranspiration = Kc.Eto

Kc = crop factor

Eto = Maximum evapotranspiration for theoretical crop

Ma = available soil moisture in the soil zone

Mca = maximum soil moisture available in the soil (at field capacity)

P = parameter denoting fraction of available moisture required to be present for

Ea to equal Ep

and the rest are as defined earlier.

Surface run off

$$Rus = R – I$$

where Rus is the the direct surface runoff

Deep seepage

$$Sd = I – deltaM$$

where Sd = deep seepage

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[9] Paranjape et al. (2001).

[10] SOPPECOM and VIKSAT (2003).

deltaM = change in soil moisture storage in the root zone

Return flow

$$Sd = Rur + Gwr + Ia$$

where Rur = return flow contribution to run off

Gwr = Groundwater recharge

Ia = Initial abstraction of moisture to compensate for loss of moisture from the entire soil during the non-crop period.

Critical daily rainfall parameter based modification of Haan model

Another way of modifying and simplifying the Haan model is through defining a critical daily rainfall parameter. This simplification assumes a characteristic critical *daily* rainfall figure associated with every piece of land, a parameter that may not be necessarily identical to the maximum infiltration rate or the average infiltration rate. This is somewhat similar to Datye's modification of the Haan model for the Jaisamand catchment.

The proposed critical daily rainfall may be taken to be a parameter that combines several factors the way the parameters in peak run off estimation work, for example, as the curve number does in the SCS method for determining peak runoff, except that it may be taken to play a similar role in respect of water yield rather than peak yield. It is instructive in this respect to return to some of the factors that are taken to affect peak run off and how they tackle them.

One such example is that of Cook's model as described by Tideman. In that model a parameter is derived from the addition of the contribution of four factors to the runoff: relief, soil infiltration characteristics, vegetal cover and surface storage, and the addition of the contributions gives us a coefficient that is used to estimate the watershed runoff. The contributions are summarized in Table 6 below.

Watershed characteristics	**Runoff producing characteristics**			
	Extreme	**High**	**Normal**	**Low**
Relief	W: 40 – 30: Steep, rugged terrain, with average slopes above 30%	W: 30 – 20: Hilly, with average slopes of 10 to 30%	W: 20 – 10: Rolling, with average slope of 5 to 10%	W: 10 – 0: Relatively flat land, with average slopes of 0 to 5%
Soil infiltration (I)	W: 20 – 15: No effective soil cover, either rock or thin soil mantle of negligible infiltration capacity, less than 0.25 cm/hr infiltration	W: 15 – 10: Slow to take up water, clay or shallow loam soils of low infiltration capacity, imperfectly or poorly drained, 0.25 to 0.75 cm/hr	W: 10 – 5: Well drained light and medium textured soils, sandy loams, silt and silt loams, 0.75 to 2 cm/hr infiltration	W: 5 - 3: Deep sand or other soil that takes up water readily; very light, well drained soils, over 2 cm/hr infiltration rate

Watershed characteristics	**Runoff producing characteristics**			
	Extreme	**High**	**Normal**	**Low**
Vegetal cover (C)	W: 20 – 15: No effective plant cover, bare or very sparse cover	W: 15 – 10: Poor to fair; clean cultivated crops or poor natural cover; less than 20% of drainage area under good cover	W: 10 – 5: Fair to good; about 50% of the area in good grassland or wood land; not more than 50% of area in cultivated crops	W: 5 – 3: Good to excellent; about 90% of drainage area in good grassland, woodland or equivalent cover
Surface storage	W: 20 – 15: Surface depressions, few and shallow; drainageways steep and small; no marshes	W: 15 – 10: Well defined systems of small drainageways, no ponds or marshes	W: 10 – 5: Considerable surface depression storage; lakes, ponds and marshes less than 2% of drainage area	W: 5 – 3: Surface storage high; drainage system not sharply defined; large flood plain storage or large number of ponds or marshes

Table 6: Weightage for different runoff producing characteristics of watersheds [11]

The next step is to correlate generation of runoff with upper and lower bounds of the critical daily rainfall. Datye has used a critical daily rainfall range of between 25 and 75 mm or a corresponding infiltration capacity. We may then associate highly runoff producing conditions with the lower bound value of 25 mm and low runoff producing conditions with an upper bound of about 75 mm. These values may also be amenable to observation.

The advantage of the Haan model and its variation by Datye is that it takes account of evapotranspiration in a more rigorous manner. Moreover the Jaisamand and Sabarmati studies indicate that by their nature peak runoff estimation methods may tend to overestimate the runoff. However, for proper application of the Haan model we still need to operate with rainfall intensities over small time intervals which therefore requires either data from continuous recorders of one type or other or simulation models that convert daily rainfall figures into a simulated distribution. The latter condition is difficult to fulfil (because of lack of recording stations and validated simulation models for Indian conditions) and the critical daily rainfall method may give us a more workable intitial estimate. Moreover, being derived from a composite index, the infiltration controlling parameter is no longer restricted to soil characteristics alone.

Datye's Sabarmati model may then be modified as follows.

Infiltration

$$Rc = 15 + 75\,(1 - W/100)$$

Where: Rc = Critical rainfall
W = Composite Cook's factor based on Table 6 above.

$$I = Rc \text{ when } R >= Rc$$

$$I = R \text{ when } R < Rc$$

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[11] Tideman (1998) p. 88.

Where: I = Infiltration rate

R = Rainfall

Evapotranspiration

$$Ea = [Ma/(1-p)Mca]Ep \text{ when } R < Rc, \text{ and}$$

$$Ea = 0.5\,[Ma/(1-p)Mca]Ep \text{ when } Rc >= Rc$$

where: Ea = actual evapotranspiration
Ep = potential evapotranspiration = Kc.Eto
Kc = crop factor
Eto = Maximum evapotranspiration for theoretical crop
Ma = available soil moisture in the soil zone
Mca = maximum soil moisture available in the soil (at field capacity)
p = parameter denoting fraction of available moisture required to be present for Ea to equal Ep
and the rest are as defined earlier.

Surface run off

$$Rus = R - I$$

where: Rus is the the direct surface runoff

Deep seepage

$$Sd = I - deltaM$$

where Sd = deep seepage

deltaM = change in soil moisture storage in the root zone

Return flow

$$Sd = Rur + Gwr + Ia$$

where Rur = return flow contribution to run off

Gwr = Groundwater recharge

Ia = Initial abstraction of moisture to compensate for loss of moisture from the entire soil during the non-crop period.

Comparisons and Combinations

The four options described here all have a common origin in that they have evolved from models which aim mainly at estimating runoff yields or peak yields. When combined with evapotranspiration assessments they result in deep seepage as a residual term. However, this is a composite term that is made up of three components, groundwater recharge, return flow appearing as runoff from base flow in channels and initial abstraction. We need some estimate of these different compositions if we are to determine the individual components.

An estimate of initial abstraction has been provided in the basic SCS model and that could be used in the other models too. However, there is still a need to see how the methods sit together. Prima facie, the similarity between the methods, and the fact that all of them are aimed at runoff estimation as their main component should indicate that the estimates would be compatible. However, the differences between the models could also turn out to be significant. For example, there are studies that argue that SCS methods of working out Ia tend to overestimate its value, especially for low rainfall conditions. There are also studies to show that these values are within allowable limits of variation if the entire range of variation in rainfall conditions is considered. Some sort of postulation dependent on antecedent moisture condition could be worked into the model. However, this needs to be verified in actual studies, and that could be one of the components of the modelling that we may take up.

As far as return flow is concerned, most of the models assume a modest value for alpha, the proportion of deep seepage that returns as base flow contribution. The reason for this lies in the nature of small watersheds One of the ways of defining a small watershed is often a watershed where channel interactions are not predominant. For this reason, it is assumed that return flow contribution is small and Datye typically had suggested a value of 0.2 for alpha. However, when we come to a sub-basin level estimation, this is going to be a problem. In a sub-basin while the periphery can be tiled by small watersheds, there will be a central portion that cannot be tiled by small watersheds and where channel interactions will predominate.

Unfortunately that leaves things rather indeterminate. We have two options in this respect, to determine either one of them as a residual value. In one option we may hypothesize a higher value of alpha, treat the groundwater recharge as a residual and see whether it broadly checks out with an independent assessment of groundwater recharge. Alternatively, we may carry out an assessment of groundwater recharge and broadly check out how whether the value of alpha based on the residual estimate lies within a reasonable range.

Datye's incorporation of root zone processes in a more systematic manner is important on two counts: first, it gives us a more reasonable estimate of evapotranspiration and secondly, it is a tool for potential productivity assessment and determination of applied water needs as well. In combination with yield assessment .functions it gives us a good method of biomass planning. Datye applies a very similar model for tree stands and for field crops, bringing them both under the scope of the FAO recommended method of yield and water estimation. Datye's adoption of the evapotranspiration component of Haan's model and its modifications can thus be profitably incorporated in the other options as well.

We should take advantage here of the way we have chosen our sub-basins so that they have a structure where flow is monitored for the past few years. In the circumstances we would suggest the following provisional procedure. Calculate Ia from the Curve Number method proposed by SCS. For the return flow work out a value for alpha based on the empirical information for exit flow that is available. That leaves groundwater recharge as a residual.

Finally, we would emphasize that we do need an empirical flow pattern to which we can relate the model results. That is why it was so important to plan a study in a way in which it incorporates a terminal structure at sub-basin level where regular flow observations are routinely recorded at least on a daily basis. It is probably better to compare monthly and yearly flows over a period as recommended by the modellers, even though the actual calculations may take place at daily levels. What is essential is to have a set of empirical observations against which the model parameters may be assessed. If we have this exit flow information to empirically ground our efforts, then our common exercise will also become a step in validating, improving and refining the model we have proposed.

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