3 LITERATURE REVIEW

Hydrologic models are used most frequently to simulate or predict flows either on a continuous basis or for a particular event. Models describing water flows, water quality and ecology are being developed and applied in increasing number and variety. Hydrologists also have long been interested in the interactions between ground water and surface water particularly during periods of low flow when recharge is minimal. It would be an interesting journey down the history lane to know development of modeling science. (Hunt Bruce, (1-1983), McCuen Richard H.)

3.1 History and Development of Hydrological Analysis and Study

History of hydrology probably begins with Perreault since he is believed to have published a report (Perreault, 1674) of the first known quantitative experiment in hydrology. He discovered by comparison of measured precipitation and estimated the annual stream flow, Q of the Seine River near Paris. A modern hydrologist might be inclined to view this attempt as primitive, but it was a significant finding in its time. It was commonly believed at that time that rainfall was not sufficient to supply the flow of streams. It is also worth noting that over three hundred years later the concept of runoff as a percentage of precipitation is still widely used.

In 1844 Roberts (Dooge, 1957) was using runoff coefficients in drainage design in Ireland and a few years later Mulvaney (1851) described what is now known as the "rational formula" in a paper to the Institution of Civil Engineers of Ireland. This gives Mulvaney the distinction of presenting the first known general hydrologic model and also the model which has the longest record of continuous use by the profession. (Refer: Linsley Ray K., "Rainfall Runoff Models - An Overview").

In the field of hydrology, numbers of mathematical models were presented by the researchers. It is believed that first effort to develop a comprehensive hydrologic model was the work of Zoch (1934, 1936). Zoch was a mathematician with The U. S. Weather Bureau. The drawback of the model was that it required number of trials, required very short interval data for the simulation. Some of these requirements are such that it is rarely fully fulfilled. In such case, the model should be such that it requires minimum data for input. In the last two decades number of significant works in direction of formulating models has been attempted.

A mathematical model for coupled transient, one-dimensional open-channel flow and transient two-dimensional groundwater flow in an unconfined aquifer was developed by Cunningham (1977) based on the application of the finite-element method (FEM). The model was applied to a site-specific problem concerned with the subsurface and surface flow conditions in the region of the Truckee River in northern Nevada, both for calibrating the model and also for investigating the predictive capabilities of its computer simulation results. The model was also applied for the simulation of the geo-hydrological conditions in a hypothetical region which consisted of a stream bounded on both sides by a large unconfined aquifer with closed enclosure boundaries.

All mathematical models for simulating coupled surface-water flow and groundwater flow conditions (Pinder and Sauer, 1971, Freeze, 1972 and Cunningham, 1977) consider distinctly separated hydrological regions where the mathematical modeling of the flow conditions are formulated differently. The mathematical development of any of the existing, advanced models consider both the conservation of mass principle and the momentum principle in formulating the governing system of computational equations for the hydrodynamic conditions in the open channel, which constitutes the surface-water hydrological region of the system. However, the mathematical development of the groundwater flow conditions in the aquifer considers only the mass conservation principle, supplemented by the subsidiary law of Dupuit-Forchheimer assumption which represents the generalized form of the Darcy's Law (Bear, 1972). The solutions for the surface-water flow conditions are coupled with the solutions for the groundwater flow conditions only at the common boundary of the distinctly separated hydrological regions.

Since the governing mathematical system for transient, one- dimensional free-surface flow conditions does not apply directly to the groundwater flow conditions in the aquifer, and similarly, since the governing mathematical system for transient multi-dimensional ground-water flow conditions cannot apply to the surface-flow conditions in the open channel, two distinctly separated hydrological regions can only have two distinctly different flow regimes at all times, according to the mathematical formulations of all presently available mathematical models for the simulation of rainfall-runoff flow conditions.

Perhaps the "best" conceptual linear storage model for river basins is that developed by Clark (1945). Clark divided the basin into sub-basins by isochrones. The areas between isochrones determine a time area histogram. Excess precipitation on the basin is routed to the outflow point on the basis of the TAH and then is routed through a linear reservoir. This model is the basis for the surface water routing component of the Stanford Watershed Model (Crawford and Linsley,1962), the U.S. Geological Survey Model by Dawdy, Lichty, and Bergmann (1972) and is an alternative in the Corps of Engineers HEC-l (1970).

Each component of the hydrologic cycle for which there is a linear approximation may be represented by a tank model. The set of tanks, each representing a linear storage, may be arranged in series or in parallel. The parameters for each tank may be estimated from physical parameters or by other means appropriate for the given component. The closed form solution of the response function for some configurations of tank models can be derived. Nash (1958) obviously solved the case for a series of n equal tanks. Sugawara (1961) solved many more complex cases. In addition he discussed piecewise linear solution of kernels by use of complex geometry and multiple outlet tanks. Sugawara discussed the interpretation and estimation of the tank parameters for different components. In India works of Bhave and Ekbote, Bhaskara Datta and S.M.Sheth (Roorkee) in the direction of developing Sugwara's tank model for Indian conditions are important contribution to this field. (Reference :Dutta and Sheth, 1985)

Consciousness about artificial recharge has been increased and analysis related to recharge has been gaining importance in addition to study of surface water hydrology. Many research studies at academic and practical levels have been done time to time in different academic and government organizations in India. Works of persons like Francis R.Halls, David A.Woolhiser and V.P.Singh are significant and worth referring. Linsley has very well reviewed and examined various models in his paper 'Rainfall-Runoff model-An overview' from the aspect of historical development to the recent models used in his time. (Refer : Linsley Ray K., "Rainfall Runoff Models – An Overview")

The Joao Eduardo G.Lopes, Benedito P.F.Braga Jr. and Joao Gilberto L. Conejo, Brazilian engineers presented a simplified hydrological model. In this model parameters are related to the physical characteristics of the watershed. The model uses the concept of curve number from the Soil Conservation Service procedure to define the soil retention capacity of unsaturated zone. The error in terms of annual and monthly volumes for the calibration period of 4 years was in the range of 20 percent. The model was applied to watersheds with drainage areas smaller than 3500 square kilometers. (Reference: V.P.Singh, "Applied Modeling in Catchment Hydrology",)

In 1990's ASCE task committee on definition of criteria for evaluation of watershed models of the watershed management committee, irrigation and drainage division formulated and elaborated Guidelines or criteria for evaluation of watershed models. This paper has been published in the journal of irrigation and drainage engineering, in issue of May-June 1990.

Various mathematical models and general references on Rainfall-Runoff and Infiltration, Water Harvesting, Irrigation Water Management, Irrigation Land Management, Irrigation Water Requirement, Optimization models for crop planning, Watershed Management, Farmers' participation in Operation and Management of Irrigation schemes, Watershed Models have been developed by different researchers.

The Stanford Watershed Model-IV was the first comprehensive watershed model developed by Crawford and Linsley in 1996 at Stanford University based on different component processes. It is a continuous, complete and general watershed model and is applicable to watersheds of all types and sizes. In this model each flow is an outflow from storage and can be expressed as a function of the current storage and physical characteristics of the sub-system. One important feature of the model is that infiltration, Interflow and evapo-transpiration values are considered to vary over the watershed area but somewhat arbitrarily. The model has been widely used in water resources studies and has undergone numerous modifications, additions and revisions. The Kentucky version of the model is the best known among them.

In recent period , enormous developments in technology and computer, modeling based on remote sensing has been gaining more popularity. In 1993, an attempt was made to use GIS for groundwater resources assessment and management of Banpura district, West Bengal. A.K. Saraf, P. Kundur and B. Sharma of department of Earth science, University of Roorkee, made an attempt to investigate ground water recharge and selecting sites for artificial recharge in hard rock terrain using integrated remote sensing and GIS in year 2000. Mr. P.R. Choudhaury obtained Ph.D.

in field of integrated remote sensing and GIS for ground water study from the University of Roorkee.

The trend today in rainfall-runoff modeling is towards the physically-based distributed-parameter models. However, there is a trend at the same time towards introducing too many bells and whistle into the models because the modeler or his employer "knows" that a particular factor is important, and; therefore, that factor should be modeled.

3.2 Water Conservation Efforts and their Study

In recent past a significant awareness in the field of conservation of water resources has been observed. If we talk on international level, in 1985, a non-profit organization called IRN (International Rivers' Network) was established. In Asia, Bangladesh Center for Advanced Studies, Bangladesh, Institute for Environment and Development Studies (IEDS) (Dhaka). Green Korea, (Korea), Amur River program, (Moscow, Russia), Earth Island Institute, (Thailand) etc. are some organizations spread over the world working in the field associated with water.

Check-dams have been the heroes of watershed development programs everywhere. Check-dams are invariably down-river, down-in-the-valley structures where land is already quite productive and comparatively well served with water. It is always the upper reaches in undulating terrains that are harder to farm and therefore left to the marginal people.

Many NGOs have been actively engrossed in the field of environment and water resources particularly by the social aspects of that field. In India, Agakhan Rural Support Program (AKRSP), Auroville Green Work, Environ Conservation Center (Karnataka), Tarun Bharat Sangh (Rajasthan), N.M.Sadguru Water and Development Foundation (Dahod) are some noticeable organizations working in this field.

One of the important projects undertaken by many such NGOs is revival of river i.e. making seasonal river perennial. For this purpose check dams on suitable gorge portion as well as in the river itself were constructed. Due to this People are getting the water through out the year. According to the report of N.M.Sadguru Water and Development Foundation, River Kali - II is a local small river partly flowing through Dahod Tehsil and partly Jhalod Tehsil of District Dahod, Gujarat. Before half a century river was perennial and after due passage of time becomes seasonal. Due to efforts of Sadguru foundation, it is now perennial. This was done by constructing series of check dams on river. In Rajasthan, there is a scarcity of water. The annual rainfall is not sufficient for the needs. Rajendra Singh, Founder of NGO, named "Tarun Bharat Sangh" working for the people of Rajasthan. They have constructed number of 'Jhohad' in the Basin of Arvari River. (Reference: Prof. Kshotriya Mohan, "Arvari nadi ke punerjanma ki katha") Dr. G.D. Agrawal of IIT Kanpur undertook an intensive evaluation of various impacts of Tarun Bharat Sangh's activities in 1995. One of the recent studies of Tarun Bharat Sangh's activities is that made by Abhishek Sharma (2002) (Reference Agrawal G.D., Dr., "An Engineer's Evaluation of Water Conservation Efforts of Tarun Bharat Sangh In 36 Villages of Alwar District", and Sharma Abhishek "Does Water Harvesting Help In Water Scarce Region? A case study of two villages in Alwar, Rajasthan").

In Alwar Rajasthan the rich tradition of building johads - which capture and conserve rainwater, improve percolation and recharge groundwater - was alive in the collective subconscious of the people. Just that push was provided by Mr. Rajendra Singh and his team to alter the rural environment. Tarun Bharat Sangh team with the support of the villagers and the Rajiv Gandhi Foundation created 369 "johads" (check-dams), which in turn recharged the ground water and made the river flow. After decades of sand, heat and infertility, the basin of not only Arvari but four other rivers in the region has discovered perennial water, prosperity and abundance. River Maheshwara, which used to flow during the monsoon earlier, flowed throughout the year in 2007 for the first time in 20 years. In spite of scant rainfall now the villages in the river catchment areas have enough water for irrigation and other needs. The *'johads'* brought about a drastic change in the lives of local people. Earlier the people used to migrate to Punjab and Haryana to work as farm labourers.

Efforts of N. M. Sadguru Water and Development Foundation of constructing lift irrigation schemes in East Gujarat were studied by Harmeet Saini and Barbara van Koppen (2001)(Reference: Saini Harmeet and Barbara van Koppen, "Gender in Lift Irrigation Schemes in East Gujarat, India"). Barbara van Koppen, Rashmi K.Nagar and Shilpa Vasavada studied efforts of AKRSP to provide support to the Jambar Women Irrigation Group in Bharuch, Gujarat(2001). Manas Satpathy studied small holder tribal irrigation in Jharkhand (2002).

An example of Bidar District of Karnataka is also worth mentioning here. A task force comprising professors of the Guru Nanak Dev Engineering College, senior engineers of the zilla panchayat, Ex-Deputy Conservator of Forests (Social Forestry) Manoj Kumar and the ex-Chief Executive Officer Naveen Raj Singh, designed hundreds of check dams. They have been built at one-eighth the average cost of traditional dams and are expected to last at least 100 years. Their cost-benefit ratio has been calculated to be better than that of major reservoirs. Over 200 innovatively-designed check-dams have been built across the Bidar district that has 590 villages. They have transformed the rural economy. Migration from villages to cities in Bidar has come down. An impact study found that groundwater level had gone up in the areas near check-dams. The district administration did not have to supply drinking water in tankers in summer to 63 percent of the villages in which check-dams were built where before check dam people in these villages were forced to wait for tankers.

In 12 villages, streams that had dried up for the last 20 years have come back to life. The district administration and the zilla panchayat plan to build 300 more check-dams. Ex-Development Commissioner Chiranjeevi Singh wrote every zilla panchayat in the State to adopt the new design. Five "Bidar model" check-dams built in Gulbarga. Deputy Commissioners in a few districts in Orissa and zilla panchayat presidents from Maharashtra and Gujarat visited Bidar to see these check-dams.

Similar example is of Sundapattivilai and Maavilai villages of Rajakkamanagalam. In this region people depend on the Chembakulam channel for their basic requirements. The channel also helps in recharging the adjoining drinking water wells. But, of late, due to meager flow of water in the channel, the villagers face lot of difficulty, especially during summer. To solve this problem the villagers came out with the idea of constructing a series of check-dams which will not only ensure availability of water throughout the year, but also recharge the wells alongside the channel. Collector gave sanction for the construction of two check-dams, to begin with, which have been completed and put to use of the community. Seeing the utility of these two check-dams the district administration has sanctioned two more such check-dams.

One more example we find from the Karnataka. Mr. Manibhai Desai, through BAIF Institute for Rural Development, Karnataka persuaded over 300 farmers to build small ponds. He started from Tiptur in Hassan district. It is a drought prone area given to erratic rainfall that averages 500 to 700 mm annually. The topography is undulating, varying between 50 and 100 feet. At the lower levels, coconut is about the only crop. In the early days of tube well madness that swept the country, Tiptur too joined in. Tube wells everywhere ran dry, the water table having gone down to 500 feet.

Amidst all this grimness, were the centuries old 'kalyanis', the dugout, stone lined ponds. There were quite a few of them in the area. They drained the last in the summer; often they survived the summer with some water left in them. They provided a clue. In Gujarat, BAIF had successfully pioneered the 'wadi' development model where small holders were led to sustained incomes by combining fruit trees with grain and vegetable farming on marginal lands, using little water.

Development Alternatives has facilitated the construction of almost 100 check-dams in the Bundelkhand Region (MP). In 1998 / 1999 they undertook a study to assess the benefits and appropriateness of check-dams, identify local problems, and generate baseline measures for future interventions. The check-dam projects are being evaluated within the context of a sustainable livelihoods approach. The framework for the current evaluation study is partly based on a retrospective reconstruction of original project objectives and partly on the framework for analysis of sustainable rural livelihoods set forth by the Institute of Development Studies (IDS), Sussex. This study employed indicators at the individual, household and community levels. While quantitative indicators were used to measure things such as village demographics, qualitative indicators were developed to capture quality of life issues.

A study on the ecological changes in the upstream and downstream areas of the Bharathapuzha has sought a precautionary approach towards building more check-dams on the course of the river. The two-year study was conducted by a team headed by Biju Kumar, Research Department of Zoology, NSS College, Pandalam, on the ecological changes in the upstream and downstream areas of Lakkidi and Peringottukurissi check-dams.

3.3 Participatory Irrigation Management in Gujarat

To ensure continuous and high level attention for promoting Participatory Irrigation Management (PIM) the following steps have been undertaken,

i) The Govt. of Gujarat has set up a High Level State Working Group for participatory irrigation management chaired by the Chief Secretary to develop a policy framework for introducing PIM in the state. FOs representatives, NGO representatives and academicians are members of this group.

ii) A Standing Committee chaired by the Secretary (WR) has been formed to follow up on the issues raised by the State Level Working Group. This committee also includes NGO members.

iii) District Level Co-ordination Committees for reviewing the progress of pilot projects in a district have been formed. Farmer representatives from all FOs and irrigation staff are members.

The Govt. of Gujarat issued a policy resolution (GR dated: 01/06/1995) to promote Participatory Irrigation Management in the state. The main features of this resolution are,

1. Government welcomes Farmers' Organizations (FOs) (with a minimum coverage of 50% of the command area beneficiaries) to manage the irrigation projects or even components of large irrigation project. It also welcomes NGOs to help in the work of organizing farmers and motivating them to manage the irrigation projects.

2. Ownership of irrigation projects remain with the government but FOs will have control over water, distribution and management and will have legal agreements with Government of Gujarat regarding maintenance and repairs.

3. Government of Gujarat has taken a decision that new irrigation projects will be taken up only where farmers actively participate in the planning stage of the project.

4. The government also welcomes farmer's participation in the construction, planning and design of minor irrigation schemes and canal projects. Farmers should also be ready, in case of work where

canals have to be rehabilitated and repaired, to contribute 10% to the cost of rehabilitation.

As per one report Gujarat Government has drawn up an action-plan to revive about 100 small and big rivers in drought-prone areas of the State and ensure their flow throughout the year. Most of these rivers belong to North Gujarat and Saurashtra regions and dry-up soon after the monsoon ends. Under this project, a series of check-dams will be built on each and every river at suitable places which will help in trapping the run-off water during the monsoons and conserve it thorough out the year.

The Government of Gujarat (GOG) has planned to revive about 77 rivers in Saurashtra by building about 300 big check-dams at various places along the river-bed. In North Gujarat 22 rivers including the legendary Saraswati, Banas, Rupen, Meswo, Sabarmati and others will also be revived. It is resolved to offer incentives to farmers groups for taking up responsibilities of water distribution, repairs and water charges recovery in terms of cash, or priority in agricultural inputs etc.

NGOs have been included in all workings groups i.e. from the District Level Co-ordination Committee to the State Level Working Group. In order to facilitate the active involvement of NGOs government has also provided financial support up to 90% of the cost incurred by NGOs towards the engagement of community organizers over a period of 3 years for participatory irrigation management schemes.

3.4 Modeling

Hydrology is essentially a science based on imperfect observation in a complex and sometime discontinuous domain. The range of hydrologic information is tremendous. The upper ranges include the vast scale of the meteorological phenomena, where information is based on sampling at

The design of hydrologic experiments will normally produce data by definable sets. For example, stream flow may be recorded before and after some physical change in the watershed. Data could be separated by runs of wet and dry years. A pool of data may be obtained from large and small watersheds, from urban watersheds and forested watersheds. To learn the informational makeup of these different data sets, it is necessary that all phases of recording, reduction, and analysis be performed in a systematic, invariant, and unbiased manner. A statistical model, objectively quantified, serves as a control to satisfy these requirements.

3.4.1 The Hydrologic System

Hydrologic phenomena are extremely complex, and may never be fully understood. However, in the absence of perfect knowledge, they may be represented in a simplified way by means of system concept. A system is a set of connected parts that form a whole. The hydrologic cycle may be treated as a system whose components are precipitation, evaporation, runoff and other phases of the hydrologic cycle. These components can be grouped into subsystem of overall cycle; to analyze the total, the simpler subsystems can be treated - separately and the results are combined according to the interactions between the subsystems.

For most practical problems, only a few processes of the hydrologic cycle are considered at a time, and then only considering a small Portion of the earth's surface. A more restricted system definition rather than the global hydrologic system is developed from a concept of the control volume. According to the control volume concept, a -hydrologic system is a structure or volume in space, surrounded by a boundary, that accepts water and other inputs, operates on them internally, and produces them as outputs (Chow 1988), Another definition of a hydrologic system is that by Clarke (1973). According to Clarke a hydrologic system "is a set of physical, chemical and/or biological processes acting upon an input variable or variables, to convert it (them) in to an output variable (or variables)". In the natural process, generally the input function is the hyetograph and the transfer (or system) function is a function of representative catchment action on the hyetograph.

3.4.1.1 Types of Hydrologic System

Through the following three sets of possible system behaviors, nature of the hydrologic system can be defined completely (Dooge, 1973).

(i) Linear or non-linear
(ii) Lumped or distributed
(iii) Time variant or time invariant
(IV) Probabilistic and Stochastic

A brief description of each of above is given in the following sections.

3.4.1.1.1 LINEAR AND NON-LINEAR SYSTEMS

A hydrologic system is said to be linear, if the principles of superposition and proportionality (or homogeneity) are satisfied. Non-linear system is represented by a non-linear function. The extent of non-linearity depends upon the system itself.

3.4.1.1.2 THE LUMPED AND DISTRIBUTED SYSTEMS

In a lumped hydrologic system, the spatial variability of inputs, transfer functions and outputs are not explicitly taken into account. For the lumped systems, average conditions (or values) of the input and, of the parameters are applicable. Thus, they are usually represented by an ordinary differential equation or a set of linked ordinary differential equations.

The system is said to be distributed if it accounts of spatial variations in the inputs, output) and the system parameters. The distributed systems are often mathematically represented by a set of linked partial differential equations. A theoretical solution for such as system requires complete knowledge of the initial and boundary conditions.

3.4.1.1.3 TIME -VARIANT AND TIME - INVARIANT SYSTEMS.

In a time-variant system, the input -output relationship changes with time. Hence, the analysis of a variant system is more complex. In a time -invariant system, the input -output relationship does not change with time, The form of the output depends on the form of input and not on the time at which the input is applied to the system. Thus, the analysis becomes simpler as the temporal effect or the input is not taken into account.

In watershed hydrology, the natural phenomena are mostly non linear as well as time and space distributed. Depending on the objectives of a study, *for* simplification one may consider the parameters of the system to be linear, lumped and time invariant. But in surface hydrology, the hydrologic system happens to be distributed, non-linear and time-variant in its behaviour. This behaviour of the system is the most complex one and quite difficult not only to formulate mathematically but also to solve. Therefore, the complicated natural hydrologic systems are simplified by making suitable assumptions. However, now with the availability of personal computers, such simplifications are not compelling. Depending on the degree of accuracy needed and subject to the availability of the data, complicated natural systems can be handled by researchers.

3.4.2 Concepts of Hydrologic Models

Hydrologic models are best defined rigorously in relation to the concept of a system. A system may be considered to be an ordered assembly of interconnected elements that transform, in a given time reference, certain measurable inputs into measurable outputs. Inputs and outputs are usually represented as functions of time. These functions may be continuous or discrete. Models are simplified systems that are used to represent real-life systems and may be substitutes of the real systems for certain purposes. The models express formalized concepts of the real systems.

In these models, given values of initial and boundary conditions, a set of input values will always produce exactly the same output value. The generating processes contain no random components. Operationally, however, deterministic models link with the stochastic models, since to predict outputs for the future, the possible future inputs must be stochastically generated.

Mathematical models may be deterministic, stochastic (statistical) or a combination of both. Stochastic models provide a range of solutions based on probabilities of occurrence and have found application in rainfall and flood forecasting. Deterministic models, based on cause and effect relationship of known systems and processes, are widely used.

Parametric models are compromise models in that they contain both stochastic and deterministic component processes. Deterministic models must evolve from rigorous application of physical and chemical principles, to accomplish the structural definition that nothing is left to chance. Such rigor is virtually impossible for real-world watersheds, so simpler watersheds are defined where severity is attainable. The parametric approach starts from conceptualization of processes on the real watershed, and through rigorous numerical techniques applied to observed inputs and outputs, attempts separation of deterministic and stochastic components. Secondarily, in the parametric approach, the deterministic components derived are associated with the pre-dominant physical characteristics of the watershed.

Statistical hydrologic models evolve from all three approaches to watershed modeling. Stochastic models have mathematical-statistical parameters that express specific properties of probability density functions of the random processes. Such parameters must be evaluated empirically. Deterministic models contain empirically defined parameters such as Manning's n, soil permeability, or diffusivity coefficients in turbulent transfer processes. Parametric models usually contain functions of macro scale watershed processes that are expressed by forms intended for empirical quantification.

Therefore, any model built or modified to obtain optimum values of any of its elements through rigorous statistical procedures will be considered a statistical hydro- logic model.

3.4.3 Objectives of Modeling

- To understand in a better way the mechanism of operation of Hydrologic Cycle and Water Transfer/movement phenomena.
- To predict the response under various possible future conditions and thus avoiding costly experimentation with the real system.
- To carry out fundamental research.

3.4.4 Application of Mathematical Models

Application of Mathematical Models it is necessary to consider some of the uses to which the models will be applied. The more important of these are:-

1. Completion of stream flow records.
2. Run-off prediction for un-gauged catchments.
3. River flow routing.
4. Real-time runoff forecasting.
5. Water balance studies.

For many basic hydrological applications a knowledge of river flow is of fundamental importance. Many of the models proposed in the literature have been used to compute stream flow. Short periods of concurrent rainfall, evaporation and runoff data are required and models are deemed to be successful if they are able to reproduce accurately the observed runoff data. A successful model is then used to determine runoff for periods when only the rainfall and evaporation data are available. In many areas there is insufficient data to calibrate a model and this requires the estimation of a parameter set based either on physical measurements or regionalized parameter values. The use of 'hydrologic models for real-time forecasts is becoming of increasing importance not only for flood warning schemes but also for the real-time control of complex multi-reservoir water resource systems. For these major schemes an optimal management policy for hydro-electric power generation, flood control and reservoir releases for irrigation can be achieved using dynamic programming techniques based on forecast future inflows. This procedure may be further extended using rainfall m9dels to predict possible future inflows thus providing a range of scenarios on which future management policies may be based.

3.4.5 Hydrologic Model Classification

Hydrologic models can be broadly classified into the following two categories; Physical models and Abstract models

3.4.5.1 PHYSICAL MODELS

Physical models include scale models which represent the system on a reduced, scale, such as a hydraulic model of a dam spillway and analog models, which use another physical system having properties similar to those of the prototype

3.4.5.2 ABSTRACT MODELS

Abstract models represent the system in mathematical form. The system operation is described by a set of equations linking the input and the output variables. These variables may be functions of space & time, and they may also be probabilistic or random variables which do not have a fixed value at a particular point in space and time but instead described by probability distributions. For example, tomorrow's rainfall at a particular location cannot be forecast exactly but the probability that there will be some rain can be, estimated. The most general representation of such variables is a random field, a region of space and time within which the value of a variable at each point is defined by a probability distribution (Vanmarcke, 1983).

A deterministic model does not consider randomness; a given input always produces the same output. A stochastic model has outputs that are at least partially random. Although all hydrologic phenomena involve some randomness, the resulting variability in the output- may be quite small when compared to the variability resulting from human factors. In such cases, a deterministic model is appropriate. If the random variation is large, a stochastic model is more suitable, because the actual output could be quite different from the single value a deterministic model would produce. In a deterministic lumped model, the system is spatially averaged or regarded as a single point in space without dimensions. In contrast, a deterministic distributed model considers the hydrologic processes taking place at various points in space and defines the model variables as functions of the space dimensions. Stochastic models are classified as space-independent or space co-related according to whether or not random variables at different points in space influence each other.

Deterministic models are classified as steady flow model or unsteady flow models. Stochastic models always have outputs that are variable in time. They may be classified as time-independent or time correlated.

The conceptual models, rely on theory 'to interpret' the phenomena rather than 'to represent' the physical process. These models have been involved in surface hydrology which simulates the watershed behaviour through conceptual elements. In this category, conceptual entities like linear reservoirs, linear channels and non- linear reservoirs along with their series: and other configurations have been successfully tried by various researchers. Some of the conceptual models have been proposed by Clark (1945), Nash (1957, 1960), Singh (1962), Dooge (1959), Mathur (1972), Pedersen (1980) etc. Comprehensive models based on simulation theory have also been developed e.g. H.E.C.-I (1967), Stanford Watershed Model (1966), Storm Water Management Model (1971) etc.

Complex watershed problems may be analysed by using a suitable mathematical model. 'The model adopted need be much simpler than the actual system. Such mathematical models rely on mathematical statements to represent the system and are often more useful in hydrologic studies when compared with the physical models. The relationship between watershed response and its parameters can suitably be studied with the help of mathematical models.

A mathematical model is generally developed through a four step process involving (1) an examination of the physical problem. (2) Replacement of the physical problem by an equivalent mathematical problem. (3) Solution of the mathematical problem with the mathematical techniques. (4) Interpreting the mathematical results in terms of the physical problem (Freeze, 1978, Heberman, 1977).

Another subdivision of the mathematical models comprises of the models based on the dynamic wave theory and the kinematic wave theory. These models are comprehensive in a sense that they involve most of the influencing parameters which take part in constructing the watershed response due to precipitation.

3.4.6 Choice of Model

There are two significant problems which modelers of hydrological systems have to face. The first of these is the choice of model, among the many available, for their particular requirement. Here it is important to recognize that the rainfall-runoff process is inherently spatial, non-linear and time-variant whereas many models are lumped, linear and time-invariant. The second problem is the choice of criteria by which the success of a model will be judged.

3.4.7 Development of Models

Four stages are usually recognized in the development of models. These stages are conceptualization, formulation, programming, and testing. Conceptualization covers by far the greatest bulk of effort in development of new models. This stage means the composite of all the thought processes we go through in analyzing a new problem and devising a solution.

The next stage in model development, formulation, no longer placed so severe a limitation on conceptualization. The formulation stage of model development means the conversion of concepts to forms for calculation. Formulation seems to imply a mathematical equation, or formula. Certainly, equations may be model forms. However, any algorithm, or sequence of calculations converting inputs to outputs, is an acceptable formulation. Such a sequence may contain equations, it may contain graphical relations, it may include "table look-up". It may also include highly sophisticated finite difference solutions of differential equations. Formulation is somewhat like preparation of a detailed flowchart of a problem.

Programming covers the mechanical but highly skilled efforts to translate the computational forms into a computer language. Testing, the last stage in model development covers all the steps taken to ensure that no errors are present and that computation forms and program structure are satisfactory.

In a wider context testing could also mean examination of the model to see how well it performs against recorded data. The goodness of performance is rather simple to quantify for rigorously stated testing criteria. On this quantified scale of goodness, however, it is more difficult to decide how good is good enough.

Obviously, before a model can be tested it must be quantified. The model must be able to accept numerical inputs and convert these to numerical outputs. Some numerical goodness tests can then be devised to show how well the computed numerical outputs match observed numerical outputs. An obvious question arises. How should models be quantified prior to testing? A partial, but again obvious answer is that quantification and testing should go hand in hand. Numerical values of parameters can be chosen by a series of assumptions, a trial-and-error process, until some satisfactory level of computed versus observed output test is achieved.

An objective of statistical hydrologic modeling is the formulation of means whereby information in the observed outputs is used to quantify the empirical elements of a model. Such procedures are usually called optimization techniques, implying optimum values of the parameters for the given set of outputs.

3.4.8 Process of Modeling

The process of modeling, in general, consists of the following activities:

1. Selecting important parameters involved in model.
2. Defining governing Law/s for the model.
3. Explaining the whole process in problem language.
4. Formulating the problem language.
5. Identifying possible ways of solving the equations.
6. Making reasonable changes in the assumptions.
7. Error analysis of the model.
8. Translating the final solution in problem language.
9. Comparing the predictions with available observations or data.
10. Checking results for number of trials till satisfactory results are obtained.
11. Deriving conclusions from the model.

3.4.9 Hydrological Study of River Basin and Modeling of Stream Flow

Hydrological studies for a river basin are essentially carried out to achieve the following objectives,

1. To know the response of a basin for a given precipitation input,
2. Estimation of water yield at specific locations
3. Formation of floods
4. Flood routing and flood forecasting
5. Estimation of design storm/floods for water resources structures
6. Drainage problems (storm water and irrigation) and designing drainage network and
7. Sedimentation and similar other studies.

All these are essential for integrated development of the watershed, a sub-basin or the river basin as a whole. It can easily be seen from the different objectives of studies listed above that establishing a rainfall runoff relationship constitutes an important aspect of hydrological analysis.

Hydrologists over the past two centuries have been putting concerted efforts in understanding response of a river basin or a sub basin for a given quantum of precipitation. In the latter half of 19th Century, empirical formulae were evolved to estimate the peak flood discharge from a basin where stream flow measurements are not carried out. These empirical relations were mostly based on a single parameter viz. the catchment area of the basin under study. Various empirical formulae like Dickens formula, Ryve's formula, Englis formula and Ali Nawaz Jung Bahadur formula were derived for ungauged basins for different regions of the country. With the advent of knowledge and the understanding of the hydrological processes in the total hydrological cycle the formulae were eventually replaced by techniques such as Depth Area Duration (DAD) curves, frequency analysis, unit hydrograph, synthetic unit hydrograph, instantaneous unit hydrograph and were furthered by application of a mathematical model describing the hydrological processes using either a lumped or distributed parameter approach. However, hydrological studies related to ungauged basins for establishing rainfall runoff relationship are challenging even as of today. Estimation of the abstractions from the precipitation depth is a complex process. Basin characteristics such as size, shape, slope and area of the basin, initial losses because of interception, retention and detention, evapotranspiration losses, intermittent flow and rate of infiltration, soil properties, land use and land cover are various processes and parameters which need to be considered for assessing the basin response.

Hydrologic models are used most frequently to simulate or predict flows either on a continuous basis or for a particular event. In all cases the model-computed flow is compared with the measured flow. It is recommended that both visual and statistical comparisons between model computed and measured flows are made whenever data is presented. The visual comparison, which often takes the form of graphic plots of simulated and observed flows, is a necessary first step in an evaluation. This first step provides a general overview of model performance and provides an overall feeling for model capabilities. When the performance of various models are compared or the performance of a single model is evaluated for different years, quantitative assessment is needed, which can be met using one or more statistical goodness-of-fit criteria.

Contradictions emerge regarding the various claims of model applicability on one hand and lack of documentation of these claims on the other hand. Hence, the credibility of the models is often questioned, and sometimes with good reason.

As emphasized by Forkel modeling studies involve several partners with different responsibilities. The 'key players' are code developers, model users and water resources managers. However, due to the complexity of the modeling process and the different back-grounds of these groups, gaps in terms of lack of mutual understanding easily develop. In the water resources management community a number of different guidelines on good modeling practice have been prepared. One of the most, if not the most, comprehensive examples of modeling guidelines has been developed in the Netherlands as a result of a process involving all the main players in the Dutch water management field. The background for this process was a perceived need for improving the quality in modeling.

The runoff formulation process is believed to be highly non-linear, time varying, spatially distributed, and not easily described by simple models. Considerable time and effort has been spent to model this process, and many hydrological models have been built specifically for this purpose. There are basically three approaches for hydrological modelling namely:

1. The conceptual approach,
2. The physically based approach and
3. The data driven approach.

3.4.10 Some of the Well Known Mathematical Models

Mathematical models are tools, which are frequently used in studying groundwater systems. In general, mathematical models are used to simulate (or to predict) the ground water flow and in some cases the solute / or heat transport. Predictive simulations must be viewed as estimates, dependent upon the quality and uncertainty of the input data. Table 3.1 lists most popular and models / computers programs which are frequently used by the researchers worldwide.

Table – 3.1 Some Popular Models and Their Applications

Sr. No.	Name of Model	Application Area
1	OPSET Model	Continuous stream flow simulation model.
2	TANK Model	Rainfall-Runoff model
3	HEC-I Model	Rainfall-Runoff model (Event based)
4	NETWORK Model	Flow routing model for river network
5	DWOPER Model	Dynamic Wave Operational Model
6	WEPP Model	Soil erosion, sediment yield model (Process based)
7	QUAL2 Model	Water quality, pollutant transport model
8	SCS Model	Rainfall -Runoff Model (event based)
9	WYM	Water Yield Model (Monthly basis)
10	KWM - KENTUCKY WATERSHED Model	Rainfall-runoff
11	SWM - STANFORD WATERSHED Model	Rainfall-runoff
12	SWAT	Soil and Water Assessment Tool (IIT, Delhi)
13	SWMM	Storm Water Management Model
14	MIKE LL	One dimensional model for River basin modeling
15	SHE	System Hydrological European: Distributed parameter model
16	RIBASIM	River Basin Simulation Model
17	HYMOS	Hydrological Modeling System
18	DAMBRK	Hydraulic routing of a flood wave due to a breach in dam
19	3DFEMFAT	3-D Finite Element Model of Flow and Transport through Saturated-Unsaturated Media
20	GFLOW	Analytic Element Model with Conjunctive Surface Water and Groundwater Flow.
21	FLOWPATH	2-D Groundwater Flow, Remediation and Wellhead Protection Model.

Sr. No.	Name of Model	Application Area
22	FEFLOW	Finite Element Subsurface Flow System
23	MODFLOW	Three-Dimensional Finite-Difference Groundwater Flow Model
24	AT123D	Analytical groundwater transport model for long term pollutant fate and migration.
25	AQUA2D	3-D groundwater flow and contaminant transport model
26	GMS	Groundwater Modelling Environment for MODFLOW, MODPATH, MT3D, RT3D, FEMWATER, SEAM3D,SEEP3D,PEST,UTCHEM and UCODE
27	GROUNDWATER VISTAS	Model Design and Analysis for MODFLOW, MODPATH, MT3D, RT3D, PEST and UCODE
28	MICROFEM	Finite-Element Program for Multiple-Aquifer Steady-State and Transient Groundwater Flow Modeling
29	PEST	Parameter Estimation and optimization package.
30	SLAEM / MLAEM	Analytic Element Models, Model regional Groundwater Flow in systems of confined aquifers, unconfined aquifers and leaky aquifers.
31	SUTRA	2-D Saturated/Unsaturated Transport Model
32	SWIFT	3-D model to simulate groundwater flow, heat, brine and radionuclide transport
33	SWIMV1 / SWIMV2	Soil water infiltration and movement model. Simulate soil water balance
34	VISUAL GROUNDWATER	3-D visualization and animation of site data and modeling results
35	VISUAL MODFLOW	Integrated modeling environment for MODFLOW, MODPATH,MT3D
36	WINFLOW	Analytical Steady-state and transient groundwater flow models

(Source : Ghosh N. et. al."Estimation Of Surface Water And Sediment Yield In Un-gauged Basins – Experience" and Kumar C.P., "Groundwater Flow Models")