Hydrology and data acquisition

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INTRODUCTION

It is interesting to speculate on the possible directions of future development of data acquisition within hydrology. Pessimistic voices are heard claiming that new techniques live their own fascinating lives, but do not solve actual hydrological problems. Such a situation can arise, for example, when hydrological modellers experience problems in trying to fit data sets of poor quality. The result is a tendency for models to live their own lives independent of data. There is a feeling that hydrological problems are not so much in focus any more and only methods and techniques are to the fore. There is also, on the other hand, considerable optimism that revolutionary new techniques will replace present difficult and time consuming field work for the collection of data. This optimism also embraces the possibilities offered by totally new types of data for describing areal variation patterns of hydrological variables.

Data acquisition is a subject of utmost importance in both applied and theoretical hydrology. In applied hydrology, even if a faithful model of a hydrological system is available, it cannot replace observational data but must rather complement them. In theoretical hydrology, it is observational data that allow research workers to accept or reject hypotheses about hydrological processes.

PRESENT REALITY

Some examples may be given to help answer the question "what accuracy can be obtained from existing observation networks?". The accuracy may be expressed in terms of the standard deviation of statistical error as a percentage of the mean value. Errors vary, for instance, with the time of the year, and the figures presented below are averages. It should be noted that systematic errors are not included. The first examples are taken from Norway and Sweden:

- point precipitation measurement: error 10 % (rain), 35 % (snow)
- estimation of areal mean precipitation: error (frontal rain) 10 %, (convective rain) 30 %
- estimation of areal snow cover: error (lowland) 15 %, (mountain areas) 30 %
- accuracy in estimated mean annual discharges at sites with observations: 15 %
- accuracy in estimated mean monthly discharges at sites without observations: 35 %.

In a forecasting project in the upper Indus River in Pakistan, Moser and Naef gave the following list of estimated data errors:
- point precipitation measurement: error 20-30 \% (mainly wind induced),
- estimation of the areal mean of precipitation: error 50-100 \%
- discharge measurement: error 50 \% and more during high flows
- deviation between model and reality: error 20-30 \% (if the model parameters are correct).

From experience in connection with water balance studies and mathematical modelling in the semiarid environment of Botswana, the following errors were estimated:
- estimation of areal daily mean precipitation: error 60 \%
- estimation of areal monthly mean precipitation: error 30 \%
- deviation between model and reality: error 50 \%
- accuracy in estimated mean annual discharge at observed gauges: 30 \%
- accuracy in interpolated mean annual discharge at sites without observations: 60 \%.

These conclusions are very similar to those of Moser and Naef. Data errors are often so large that they overshadow any differences resulting from the differing capabilities of various models.

Present techniques allow for a thorough evaluation of the information content, uncertainties and errors in data collection networks, although this is very seldom done or at least the figures are not given publicity. The problem can be reversed to one of collecting data in such a way that the information content is maximized or uncertainties and errors are minimized. It is, however, difficult to use statistics as an objective measure of the worth of hydrological data. A small relative decrease in the error generally demands a substantial increase in the volume of data to be collected, and the relative benefit of these new data is hard to quantify. The error terms, however, usefully indicate a minimum threshold level for the amount of collected data, but below this it is impossible to draw meaningful conclusions. The fact that errors are surprisingly large in many cases, so large in fact that we are actually below the minimum threshold, is to some extent due to inefficient instruments, observer errors and deficiencies or lack of quality control. However, the main reason for these errors is the complex structure of the patterns of variation in time and space of hydrological variables and the inability of present observational methods to record these adequately. In the past an almost naive attitude towards representativeness and accuracy of hydrological variables can be traced, especially among hydrological services. Data are accepted as absolute facts, at least when printed in a hydrological yearbook.

One development in planning data collection has been the introduction of formal schemes for optimizing the collection systems, where the gain in information from new data is balanced by the cost of its collection, and the value of more data may therefore be realistically assessed. However, such structured analysis is most readily applied to special and single purpose data collection projects, and rarely to national or even regional data collection schemes because of the complex objectives involved. There are thus many difficulties to be faced in the application of these methods and it is all too easy to criticise their use in any particular
instance. Certainly, there was a time when the attitude towards data collection among hydrologists was "the more data, the better", and for many years data collection activities continuously increased. In most countries the peak has been reached and the trend has changed. As networks have grown the purpose of their existence has become more general and difficult to describe in simple terms compared with the initiation of observations when each station was directly related to a specific water project. The economic value of hydrological maps, design values, environmental and hydrological control and forecasts can be difficult to evaluate, but they are nevertheless of great importance and are essential for the rational socio-economic development of any country. However, figures of accuracy and possible error will not of themselves convince any government to reverse the new trends and to maintain viable data collection systems. Floods and droughts, which strike countries more or less regularly, have in the past motivated the establishment of observational networks. It is doubtful whether this will be so in the future. It is unfortunate that we should ever have to rely on such tragic events to highlight the need for hydrological data. Logical argument, objective facts and continual pressure will need to be applied if national data collection systems are to be retained and augmented to meet the data needs that exist and can be forecast with some confidence.

It is the heritage of the past traditions and techniques, rather than the need of data for a specific problem, that tend to guide to a large extent what is measured and with what time and space resolution. It is obvious that fundamental measuring problems exist within hydrology, and the problems to be faced in accounting for complex variation patterns have already been mentioned. Examples of processes that are poorly measured today are: flows in the unsaturated and saturated zone, in situ hydrogeochemical processes and suspended sediment. Measurements in extreme conditions are also problematical. It is possible today to observe variations in time more accurately than those in space. This can be explained to a great extent by technical constraints, but not fully, since tradition also has a major role to play here. It is easier to build a permanent observation station with good time resolution than to sample many observation points in space at a few instances in time.

Our theoretical concepts of hydrological variability use continuous functions or infinite sequences, while the related hydrological data are highly discrete and finite in character. Observations are considered as points in space and time. Table 1 offers some examples of hydrological methods for direct "point" observation and indicates their locality and the resolution in time and space. It is immediately apparent from Table 1 that point observations represent some fraction of space and time. This fraction varies from dm and dm to m and m in space, and from minutes to hours in time. For certain variables especially in the atmospheric boundary layer, a point observation can represent still larger areas or volumes. The time and space resolutions are of course closely related. Table 1 considers standard instruments, but more advanced methods can change the scales of resolution. In addition to the direct observational methods that are given in
Table 1, indirect methods may also be used. This means that one or several other variables are observed, and from these the desired hydrological variable can be determined by a more or less complex computational procedure. Such indirect methods are listed in Table 2 together with their time and space resolutions. The computational procedure is also briefly mentioned. Many methods, especially remote sensing and those including radioactive chemicals, are based on very advanced theories for the calculation of the desired hydrological variables.

**TABLE 1 Examples of direct methods for "point observations" of hydrological flows (velocities) and states (levels, potentials, quality)**

<table>
<thead>
<tr>
<th>Observational method</th>
<th>Variable</th>
<th>Locality</th>
<th>Time resolution</th>
<th>Space resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocities and flows</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation gauge manual reading</td>
<td>Precipitation intensity</td>
<td>Atmospheric boundary layer</td>
<td>hours</td>
<td>dm</td>
</tr>
<tr>
<td>Pluviograph</td>
<td>&quot;</td>
<td>&quot;</td>
<td>minutes</td>
<td>dm</td>
</tr>
<tr>
<td>Evaporation pans</td>
<td>Evaporation intensity</td>
<td>&quot;</td>
<td>hours</td>
<td>m</td>
</tr>
<tr>
<td>Evaporimeter</td>
<td>&quot;</td>
<td>Upper soil layer</td>
<td>hours</td>
<td>m</td>
</tr>
<tr>
<td>Lysimeter</td>
<td>Evaporation and/or infiltration intensity</td>
<td>&quot;</td>
<td>hours</td>
<td>m</td>
</tr>
<tr>
<td>Infiltrometer</td>
<td>Infiltation intensity</td>
<td>Upper soil layer</td>
<td>hours</td>
<td>dm</td>
</tr>
<tr>
<td>Current meter</td>
<td>Water flow</td>
<td>River</td>
<td>minutes</td>
<td>dm</td>
</tr>
<tr>
<td>States</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snow stake</td>
<td>Snow depth</td>
<td>Lower atmospheric boundary layer</td>
<td>hours</td>
<td>dm</td>
</tr>
<tr>
<td>Snow tube</td>
<td>Snow density</td>
<td>&quot;</td>
<td>hours</td>
<td>dm</td>
</tr>
<tr>
<td>Snow pillow</td>
<td>Snow water</td>
<td>&quot;</td>
<td>minutes</td>
<td>m</td>
</tr>
<tr>
<td>Tensiometers</td>
<td>Soil suction</td>
<td>Upper soil layer</td>
<td>minutes</td>
<td>dm</td>
</tr>
<tr>
<td>Observation tubes</td>
<td>Groundwater level</td>
<td>Ground</td>
<td>minutes</td>
<td>dm</td>
</tr>
<tr>
<td>Stage gauge</td>
<td>Water level</td>
<td>River</td>
<td>minutes</td>
<td>dm</td>
</tr>
</tbody>
</table>

If one considers the errors associated with different methods of observation, it is still generally the case that ground-based observing stations provide the most accurate data. Remote sensing is beginning to be used in hydrological models, but for the most part the applications are cartographic in nature. About the only areas where remote sensing has as yet made a real impact on hydrological modelling are those where the primary interest is in land use and snow cover. Tables 1 and 2 have been arranged according to observational methods. An alternative would be to base
### TABLE 2 Examples of indirect methods for "point observations" of hydrological flows (velocities) and status (levels, potentials, quality)

<table>
<thead>
<tr>
<th>Observational method</th>
<th>Observed variable</th>
<th>Determined variable</th>
<th>Locality</th>
<th>Time resolution</th>
<th>Space resolution</th>
<th>Method of determination</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Velocities and flows</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Determination from other direct observed flows and states</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Radar</td>
<td>Intensities in radar echoes, precipitation intensities in pluvigraphs on ground</td>
<td>Precipitation intensity</td>
<td>Lower atmospheric boundary layer</td>
<td>minutes</td>
<td>100 m</td>
<td>Relation radar echoes intensity</td>
</tr>
<tr>
<td>Calculated potential evaporation</td>
<td>Radiation intensity, wind speed, air humidity, temperature</td>
<td>Potential evaporation intensity</td>
<td>&quot;</td>
<td>minutes</td>
<td>10 m - 1 m</td>
<td>Penman's methods</td>
</tr>
<tr>
<td>Calculated actual evaporation</td>
<td>a) &quot;</td>
<td>Actual evaporation</td>
<td>Lake</td>
<td>minutes</td>
<td>10 m - 1 km</td>
<td>Energy balance method, vertical profile method</td>
</tr>
<tr>
<td></td>
<td>b) Other water balance variables</td>
<td>&quot;</td>
<td>Catchment</td>
<td>weeks</td>
<td>km</td>
<td>Water balance equation</td>
</tr>
<tr>
<td></td>
<td>c) Potential evaporation, soil physics</td>
<td>&quot;</td>
<td>Soil profile</td>
<td>days</td>
<td>m</td>
<td>Thornthwaite's Budyko or other water balance methods</td>
</tr>
<tr>
<td>Calculated water discharge</td>
<td>Water level</td>
<td>Water flow</td>
<td>River</td>
<td>minutes</td>
<td>hours</td>
<td>m</td>
</tr>
<tr>
<td>Gradient calculations from observed levels or potentials</td>
<td>a) Water level, river roughness</td>
<td>Water velocity (flow)</td>
<td>minutes</td>
<td>100 m</td>
<td>Manning or Chezy formula</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
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<td></td>
</tr>
<tr>
<td>b) Water level, permeability</td>
<td>&quot;</td>
<td>Ground</td>
<td>hours</td>
<td>100 m</td>
<td>Darcy equation</td>
<td></td>
</tr>
<tr>
<td>c) Soil water content</td>
<td>&quot;</td>
<td>&quot;</td>
<td>minutes</td>
<td>dm</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>Mass transport calculations</td>
<td>Water flow, concentrations</td>
<td>Mass transport intensity</td>
<td>&quot;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>River</td>
<td>Ground</td>
<td>hours</td>
<td>m</td>
<td>Relation water and mass flow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Model for mass transportation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>B Tracer</td>
<td>Natural isotopes (D, O)</td>
<td>&quot;</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>a) &quot;</td>
<td>&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) &quot;</td>
<td>Mixing relations</td>
<td>&quot;</td>
<td></td>
<td>Model for dispersion</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) &quot;</td>
<td>Water flow velocity (flow)</td>
<td></td>
<td></td>
<td>Model for mixing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
<td></td>
<td></td>
<td>Model for dispersion</td>
<td></td>
</tr>
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<td></td>
<td>&quot;</td>
<td>&quot;</td>
<td></td>
<td></td>
<td>&quot;</td>
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</tr>
<tr>
<td>Injected tracers</td>
<td>a) Fluorescent dyes salt, tritium</td>
<td>&quot;</td>
<td></td>
<td></td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) Salt, tritium</td>
<td>&quot;</td>
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<tr>
<td></td>
<td>c) Salt, tritium</td>
<td>&quot;</td>
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<tr>
<td></td>
<td>d) Tritium</td>
<td>&quot;</td>
<td></td>
<td></td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>State</td>
<td>A Observation of radiation, dampened or reflected</td>
<td>Damping in radiation intensity</td>
<td>Water content in snow</td>
<td>Atmospheric boundary layer</td>
<td>minutes</td>
<td>m - 100 m</td>
</tr>
<tr>
<td></td>
<td>Natural f -radiation</td>
<td>Reflected radiation intensity</td>
<td>Soil water content</td>
<td>Upper soil layer</td>
<td>minutes</td>
<td>dm</td>
</tr>
</tbody>
</table>
them on the theoretical flows and states that we need to study if we are to solve hydrological problems. In such a table, an attempt could be made to see how many of these variables it would be possible to observe directly. Such a table would contain many empty spaces and question marks.

One can note many very different concepts of variability in geophysics and geography. The continuous variation patterns involving many scales of motion as found in meteorology contrast with the mosaic structure used in geography, with its drastic changes from one locality to another. Hydrology lies in between these two since it sometimes treats continuously varying phenomena, and in other cases it works with mosaics. Of critical importance is the relationship between, on the one hand, the size of a specific hydrological system and, on the other, the scales of the landscape elements together with the underlying hydrological processes. These relationships are rarely investigated, because of a lack of relevant data. It can be stated that, among the barriers to future development of theoretical hydrology, one of the most critical is the lack of data necessary for identifying and verifying theories. It is not uncommon to be faced with superfluous information about the variation in hydrological processes with time while there are gaps in our knowledge of variation patterns in space.

A central concept in hydrological data collection has been that of representative observations. We have noted that hydrological phenomena are considered to be continuous in space and time but observations are often made as point values, and there exists a significant difference between our theoretical view of hydrological mass flows and states and what can actually be observed directly or indirectly. Point observations are not as a rule "points" in time or in space but represent some temporal interval or some spatial surface. This situation need not be a problem when studying individual hydrological variables, but may cause difficulties when, for instance, balances involving several variables are being evaluated and it is necessary for the observations to represent the same interval in time and the same surface in space. In the past, there has been very little awareness of these differences between theoretical variables and what we observe, including their resolution in time and space. The concept of representative observations is widely used, but it still needs to be studied and more clearly defined, particularly in relation to point and areal processes.

**FUTURE PROSPECTS**

There are several future scenarios for the year 2000 that could drastically change the present situation, for example, deficiencies in the manual collection of data, including quality control and archiving, may be overcome by the automation of instruments and the real time on-line acquisition of data. This is of special importance even now in developing countries where the "traditional" data collection techniques face large problems leading to a significant trend towards decreasing observational activity and
resulting in data sets of very uneven quality. The future of traditional methodologies is therefore uncertain and the only hope, in many instances, lies with fully automated on-line observation systems for archiving data. For logistical and technical reasons we are likely to find that data are collected in real time or not at all. For quite different logistical and technical reasons, this scenario will possibly also apply in developed countries. Data for forecasting purposes are already collected in real time to a great extent, but these data are not always archived. At the same time, instruments are becoming increasingly automated, and logic demands that data should not be collected twice. Meteorologists are ahead of hydrologists in this regard, although climatologists still find themselves collecting data which, at least in theory, should be available from synoptic networks but are not archived.

In the field of data transmission many alternatives have become available, including direct wire, telephone, radio, microwave telemetry, satellite relay and meteor-burst. All are applied in practice today and their feasibility for operational use will be further improved by the year 2000. Furthermore, microprocessors will play an increasing role in automated systems. Microprocessors and semiconductor memories used in conjunction with instruments will provide for data storage and for the possibility of carrying out some data processing, such as the application of calibration functions and quality control, at the observation site.

The total number of ground-based observation stations will be reduced, this is almost inevitable. The critical minimum threshold level will, however, no longer have the same relevance because ground-based stations will be included in large data collection systems where spatial resolution will be taken care of by the integration of remotely sensed data. Such data will build on and enhance the value of data obtained from ground-based instruments, but they will not replace them. Those ground stations that remain will thus have an increased importance. The transition from traditional methods to data collection systems containing spatial data with high resolution will result in ever greater volumes of data, and this will pose problems for storage and analysis. Redundant information will be eliminated by only recording changes in continuously monitored parameters plus significant events.

One obvious future development is that new techniques will increase the accuracy of observations as well as their time and space resolution. Totally new techniques are probably to be found among indirect methods which still demand theoretical development. New techniques will certainly compensate for the present lack of knowledge of spatial variation patterns. There is a potential breakthrough in applied hydrology through the use of microwave, infrared and gamma radiation remote sensing. These techniques provide more than cartographic information and can tell us a great deal about the state of a watershed, i.e. how wet or dry and how cold or hot it is. They will provide data on spatial patterns of soil moisture, precipitation and evapotranspiration.

Ground-based weather radar, used in conjunction with automated ground-truth raingauges, will provide quantitative information on rainfall patterns. Snowfall measurement will probably continue to
be problematical partly because of unstable radar echoes, but most of all because of inaccurate ground observations. Satellite-derived data on areal precipitation are likely to be of great value for hydrological forecasting, especially in developing countries. Current sensor values cannot be interpreted directly in terms of soil moisture and groundwater variables, but only in terms of soil classes. A further refinement into wetness classes is therefore foreseeable.

Evapotranspiration is a field of common interest for meteorologists and hydrologists. Any use of remotely sensed data in this area requires that they be interpreted using more or less sophisticated models of heat-mass exchange in the atmospheric boundary layer. It is believed that the further development of these types of model is critical for future progress in this field. The use of remote sensing in data collection systems brings to the fore the problem that was mentioned earlier of representative observations. The first question is whether all sensors in a system reflect exactly the same physical phenomenon. The second relates to how different sensors average over an area and how large those areas are. Effective methods are needed to combine point, transect and areal hydrological measurements because all these will exist side by side in future data collection systems.

The most drastic changes during recent years have been in relation to the availability of basic hydrological data for further use and analysis. Hydrological data processing is already highly computerized in most countries. Microprocessors, computer graphics, colour plotters, user-friendly computer software, mini- and microcomputers are facilities that are already in use by hydrologists. Even if no revolutionary new technology appears in the near future, the present techniques will improve and become more easy to operate. Fast, more powerful and cheaper computers, in particular microcomputers, will be available with improved compatibility. The development of hydrological software will continue to be ever more user-friendly and more easily transferable, and to involve increased use of plotting facilities and computer graphics. Similarly, we can expect improvements in primary processing, storage and retrieval techniques and data exchange.

We can also expect a continuing trend towards the increased integration of a range of data of different types and from different sources in the solution of specific hydrological problems. These data will include observations from integrated systems using remote sensing and ground-based stations, which monitor hydrological variables, and geographic and cartographic information from land survey databases and/or from earth resources satellites. Meteorological variables will be derived from a new generation of operational models incorporating boundary layer and high resolution limited area models. The latter models already use the two other types of data mentioned as model inputs.

Present cartographic techniques are highly computerized. Modern topographic maps are produced from digital terrain models with resolutions of 10-50 m. As the production of new maps continues, many countries in the year 2000 will be completely covered with these types of terrain data. The accuracy and reliability of these
data are superior to satellite data used for the same purpose. The latter type, on the other hand, are frequently updated. Together, they form an enormous resource for hydrological applications.

A field which has evolved slowly, up until now, deals with hydrological information systems for design and planning purposes. The availability of new data types should speed up this development. Hydrological databases today are independent units but the trend is obviously towards integrated databases. Hydrology becomes only a part of the database for water management or a still smaller part in databases for environmental control and natural resources. This development will provide hydrologists with new types of data. Most important could be the high resolution digital information on the landscape, which has already been mentioned. However, it may become difficult to support specific hydrological interests, since what we as hydrologists will look upon as sophisticated models will be treated as just one among many procedures for the interpolation of data. We should be concerned to ensure, as far as we can, that these interpolations make hydrological sense. In any event, this development will allow great flexibility in obtaining relevant information which is also presented in a manner that is easy for the layman to understand.

Will classical hydrological yearbooks be issued in the year 2000? Maybe they will, but probably only to keep up the old traditions. The tendency is clearly towards more processed products in which the traditional type of hydrological observation is only a small part. Other types of data together with mathematical models will become important in this process. Original observed data will no longer be routinely supplied. In their place, we will find multicoloured maps and diagrams for each specific applied purpose. The customer for hydrological services will be able to obtain those directly through his personal computer for further analysis and for application.

In characterizing the present situation, the availability of data is considered as a barrier for theoretical development. In many fields of hydrology the situation may be reversed and we may be faced with a surfeit of data that cannot be fully used due to a lack of appropriate theories and models. This lack will be highlighted by the situation mentioned earlier where data from many different sources are likely to create interface problems. These questions will be one of the main fields of research in the future. The availability of new types of data has another aspect, since it may make it possible, for example, to improve the efficiency of rainfall-runoff modelling. Time invariant catchment parameters that need to be collected only once can reduce the need for long continuous rainfall-runoff records. At least we can be sure that the future will see a more flexible attitude towards data collection.

**TRENDS AND CONSTRAINTS**

The pace and direction of development will be different between countries, as it will be strongly influenced by factors such as the local economic situation, national development policies, tradition
and the particular problems faced by each country. Economic stringencies are at the root of the present decay in hydrological observation activities. In many situations the unwillingness of society to finance hydrological activities is a consequence of inadequate recognition of the need for and contribution of these activities to the national economy. It is hoped that the wave of technological development will make it easier to motivate support for new systems of data collection and processing than has been the case for the traditional existing activities. It will be rare indeed to obtain support for both. Whether we want it or not we are likely to be forced to accept severe cuts in traditional methodologies and to see these replaced by new technology or by none at all. There is of course no a priori guarantee that new methods will be superior to existing ones. For example, a distributed model using remotely sensed data may not give as good results as a well tried model using accurate ground-based measurements.

Important factors in data acquisition are continuity and the maintenance of the operational system. There are many examples in hydrology of systems that have failed because insufficient attention has been paid to logistics and the costs of maintenance. There is also today some uncertainty with respect to satellite programmes and their future operation, including the types of data they will collect and under what conditions the data will be made available. It is difficult to forecast the future in such cases because it depends not only on future technological developments but also on the evolution of national and international policies in this regard. National planning and development policies will of course have an enormous influence on all aspects of operational hydrology. In the past, operational hydrology has not only suffered from a general lack of funds but what funds it has had available, have all too often been drastically reduced at times of economic or social crisis. Scientific and technical arguments in favour of continuity of data collection unfortunately carry little weight under such circumstances. We have no particular reason to believe that this situation will change in the future, but we can hope. We can do more than just hope when changes in national policy are announced in advance; we can plan for a loss-minimizing reduction in activities or, if resources are to be increased, we can phase in new activities as and when they will be most beneficial. Even when no advance notice of a policy change or cut in funds is expected, it is still possible to draw up contingency plans as to what to do if such an event occurs.

National policy and availability of funds is perhaps most important with regard to personnel: their numbers, their salaries and their level of training. The demand for trained and specialized personnel will be even higher than today. There is already a lack of trained personnel who can make use of the new technologies. This contributes to the widening gap that exists between developed and developing countries and to the marked gaps that also exist between individual countries within these two groups. Education and training, coupled with manpower policies, will be of the utmost importance to the future of hydrological data collection. The general trend in technological development as a whole is towards
technical centres where knowledge and facilities are concentrated. For hydrologists, as well as others on the periphery, it can be difficult to utilize properly some technologies. The conflict between centre and periphery may create large problems for the future. It may arise within a country as well as between countries throughout the world, but it is likely to be most accentuated in developing countries.

There is considerable interest in research on new techniques for hydrological applications from space technology and other challenging fields of scientific development. Less effort is directed to basic research in hydrology and to the implementation of new techniques in operational practice. It is natural that hydrologists prefer to develop ever more sophisticated procedures rather than engage in the much less stimulating task of transferring existing knowledge and technology to potential users and of formalizing new techniques for routine application. This tendency, if it continues, will hamper the widespread use of new techniques.

CONCLUSIONS

It is difficult when discussing future development not to comment on tendencies from a normative prescriptive point of view, indicating which of the possible outcomes are the most desirable. We have shown a scenario for a drastic shift in technology for data acquisition. It is logical to propose that the new methods should only be introduced when and where their advantages over current techniques can be clearly demonstrated on both technical and economic grounds. We should of course not hesitate to take advantage of the benefits offered by these new techniques. However, a total commitment to automation and computer-based techniques could place future development well beyond the reach of many countries due to the related requirement for economic resources, technical facilities and trained personnel. A flexibility in attitude towards manual and automatic procedures and towards basic and sophisticated techniques will certainly be needed in the future.

The competition for financial support for various activities will probably be even sharper in the coming period than it is today. One of our most important tasks as hydrologists in the future will be to educate the public and to advise decision makers that insufficient knowledge in our field can jeopardize the plans for our own welfare and for economic development, and could even increase the risk of loss of life and damage. The message should be that there is a need for hydrological data as a basis for water resources management, as a contribution to environmental control, in hydrological forecasting and in the planning and management of most of society’s activities. We can highlight this message by showing the benefit of our activities to the economy and in improving safety against loss of life and damage, but also by broadening our traditional fields of activity so as to ensure that what we produce is useful not only to small groups of experts but also to society at large. The success of these attempts will influence very much the future development of hydrology.