ANALYSIS OF ANNUAL RUNOFF MAPS

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INTRODUCTION

Colour coded maps of annual runoff for British Columbia have been produced for the years 1966 to 1979 inclusive. These maps provide a visual display of one aspect of hydrologic response but are not amenable to quantitative analysis.

This memorandum proposes a study involving the quantification of the pictorial information contained in the runoff maps. The ensuing analysis of the quantified information should allow an examination of the ability of the hydrometric network operated by the Water Survey of Canada to sample and represent the runoff process.

The proposed study is a pilot to ascertain whether the commitment of large scale resources in terms of time and computer programming would be worthwhile.

The arrangement of this proposal is:

1) to briefly review the concept of digital images, providing an introduction to commonly used terms;

2) to outline the major analyses that can be performed on digital images; and

3) to indicate extentions to the analyses which will integrate with and advance other hydrologic studies being planned and undertaken by the Hydrologic Studies Section under the mandate to develop information transfer and network evaluation techniques.

DIGITAL IMAGES

An image, in the context of this memorandum is a two-dimensional intensity function, g (x,y), where g, the amplitude at the point (x,y), represents runoff. The image is, in these studies, of a response field rather than of a physical object, ie. a cat.

Few naturally occurring intensity functions may be described in analytical form, for example a polynomial. Therefore, representation is accomplished by sampling the intensity function at discrete points in the x - y plane (Duda and Hart, (1973) Chapter 7). The simplest sampling method is to partition the picture plane by quadruled grid and to take the intensity function at the center of each square, Figure 1, so the continuous curve is represented by a series of discrete values.

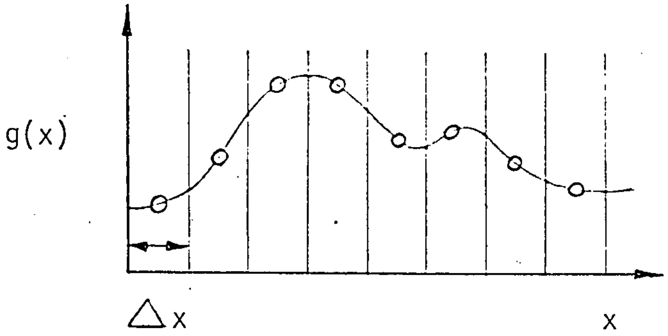


Figure 1 A One-Dimensional Sampling of the Intensity Function g (x) g (x) could be the voltage from a sensor.

The quadruled grid divides the picture plane into cells or picture elements (abbreviated pixels). In Figure 1 the pixel dimension is Δx.

Another method of sampling is to assign the mean value of the intensity function over a pixel. Depending upon size of pixel and behaviour of the intensity function within a pixel, this procedure may yield a value different from the first sampling procedure, Figure 2.

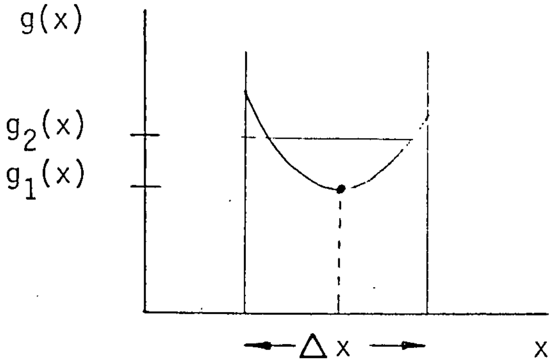


Figure 2 Effects of sampling schemes

$g_2(x)$ is sampled value by mean value

$g_1(x)$ is sampled value for centre of pixel

Sampling produces spatial quantization. Fine sampling or small pixel size is required to closely represent a rapidly changing intensity function while a larger pixel size will represent a slower changing intensity function. There are some analytic procedures to guide the selection of pixel size or sampling interval, based upon the maximum rate of change of intensity required in the image.

Measurement of the intensity function is significant. For example, the runoff data which forms the annual runoff maps is of variable resolution, ie. the drainage basins are for various areas. For larger basins, fine detail of runoff will be averaged out; the runoff image is blurred. Large areas of uniform colour on the runoff maps may represent uniform runoff or averaged runoff in regions which are sparsely gauged.

Figure 3, from Gonzalez and Wintz (1976), illustrates the effect of pixel size upon the image. N is the number of pixels per axis, so each image is N x N pixels. For image 3a, N is 512 pixels; for image f, N is 16 pixels. The resolution (degree of discernable detail) of an image is strongly dependent upon N. But the number or size of pixels is much less critical in the background than in the area of the astronaut. So if either the sensor or sampling process forming the image has large or coarse resolution, certain areas of the image may be degraded while others, ie. the background of the previous example, are unaffected. This observation is the basis of resolution-dependent information measures for image analysis, Wong and Vogel (1977).

As well as spatial quantization, there is quantization of the intensity. That is, the response range of the intensity function is portioned into a set of discrete levels. For example, for the annual runoff maps, colours were assigned ranges of runoff.

Annual Runoff	Colour
0 - 125 millimeters	yellow
125 - 250 millimeters	light green
250 - 400 millimeters	dark green
400 - 650 millimeters	pink
650 - 1000 millimeters	orange
1000 - 1500 millimeters	red
Over 1500 millimeters	purple

Figure 4, from Gonzalez and Wintz (1976), shows the effects of changing the number of quantization levels. Figure 4-h with 2 levels is sometimes referred to as a binary image.

There is no theoretical guidance for the number of levels for intensity quantization, usually a compromise between accurate representation

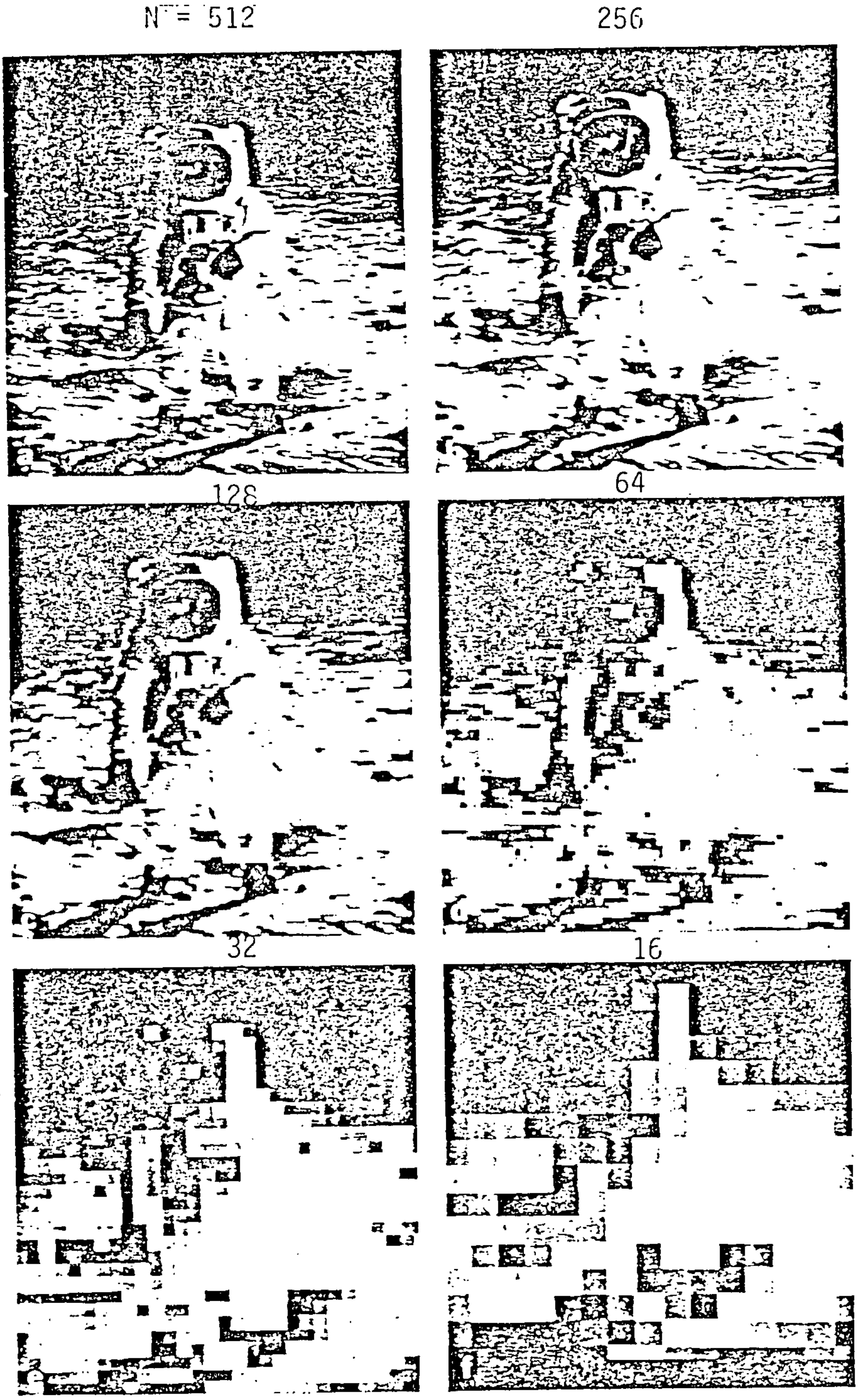


Figure 3. Effects of changing sampling-grid size.

and keeping computational requirements within reasonable bounds.

In summary, digital images have three important parameters; pixel size, number of levels of quantization, and resolution of the sensor forming the image. These parameters are not independent. The proposed study is aimed at examining the effects of these parameters on the representation of annual runoff in British Columbia.

2. IMAGE ANALYSIS

Figure 5 provides an outline of image analysis procedures. The digitization has been discussed in the section of digital images. Enhancement and restoration techniques deal with improvements of a given image for either human or machine analysis. These procedures attempt to produce an image more suitable than the original and are very much problem dependent. If, for example, an image was considered to be noisy, ie. the digital values in the pixels were not good representations of the image, then some procedure to decrease the noise would be applied.

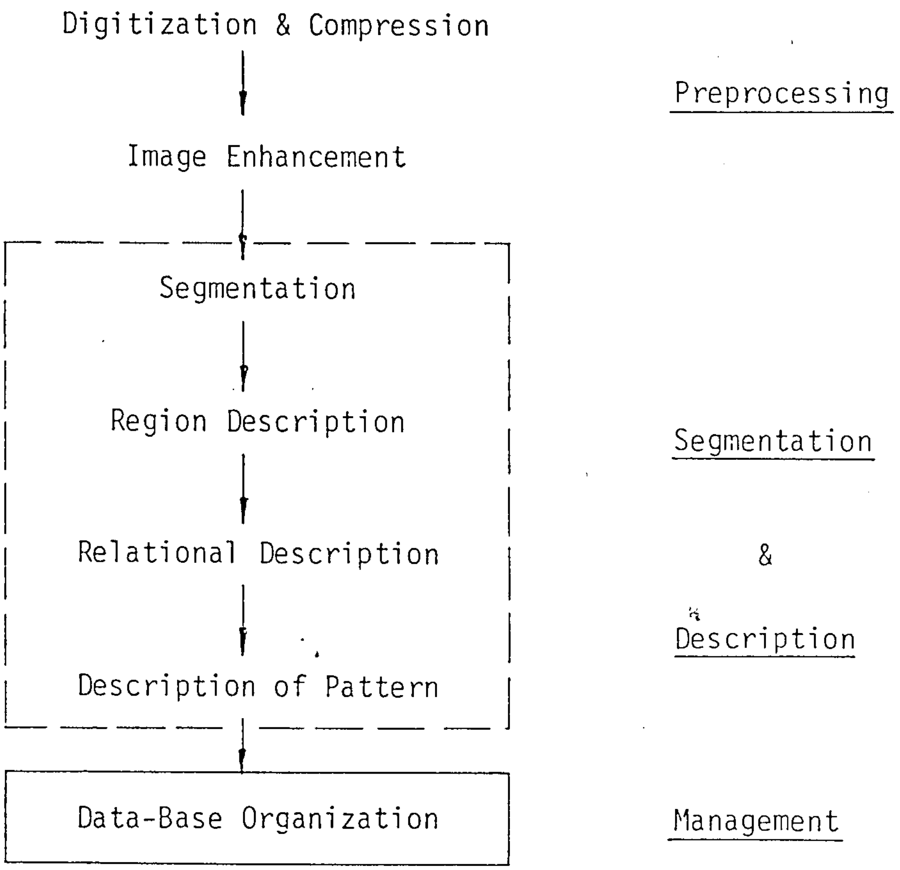
Segmentation deals with decomposition of an image, in these studies into hydrologic regions, or geographic areas with similar runoff process. The region descriptions could be made in terms of texture analysis or a probability distribution of the runoff values in the pixels of the region.

Segmentation could also be studied in the temporal domain, by identifying geographic areas of the province in which the runoff changes considerably from year to year.

Relational description involves description of the runoff process in terms of other sources of data, for example meteorological and physiographic. The relation may also be in terms of models for runoff, describing areas of the province for which runoff modelled from meteorologic and physiographic data is similar to measured runoff and areas of the province for which modelled and measured runoff are dissimilar.

Data-base organization refers to the ordering of the data necessary to produce and analyze the runoff images.

Figure 5 Major Image and Scene Analysis Procedures



The first step in the analysis of the runoff maps is digitization. Digitization requires quantization in space and in level. The simplest method is to choose a pixel size, for example, 1^o latitude by 1^o longitude. Then, from the colour code and the area of each colour in the pixel, estimate the mean runoff. The areas can be reasonably estimated from a random dot pattern. This digitization can of course be improved upon but only with considerable work of setting up files on drainage basins.

No enhancement or restoration is planned at this exploratory level although it is recognized that noise may be introduced in the digitization process.

To segment the image into hydrologic regions, a search will be made for large gradients in the runoff from pixel to pixel. Large gradients should occur at boundaries of hydrologic regions.

With reference to Figure 6, the simplest approximation to the magnitude of the gradient for a pixel (i,j) is the Robert's cross operator, R (i,j).

Note: The conventional coordinate system for digital images starts at top of image and scans left to right. Pixel (m,n) is in row m column n.

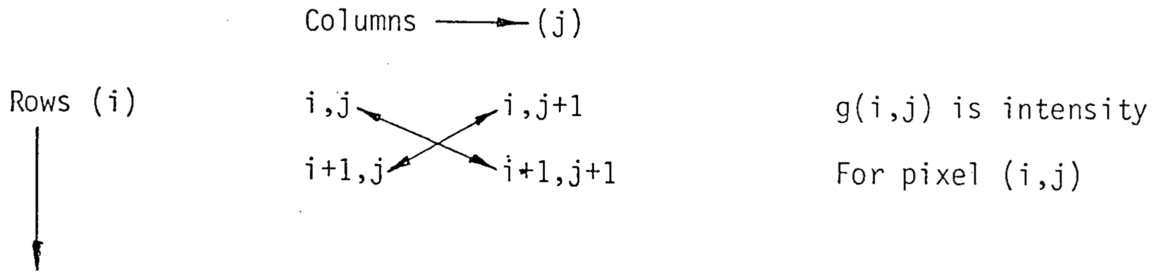


Figure 6 Gradient Estimation Scheme

The directional derivative in each direction is approximated by simply subtracting adjacent elements. The Robert's cross operator is often simplified for computational efficiency by using absolute magnitudes, ie. $F(i,j) = abs\ (g(i,j) - g(i+1,j+1)) + abs\ (g(i,j+1) - g(i+1,j))$.

Pixels in a region with little runoff variation will have low gradients. Pixels in highly variable area, ie. the boundaries of hydrologic regions, will have large gradients. The question is how large, so a threshold must be introduced. There is no guide for the size of the threshold, so various values will have to be tried. Segmentation does depend upon threshold. Set high, there will be only one region; set low, every pixel could be its own region. Obviously, this is an empirical situation but the procedure does provide a means of investigating regionalization of runoff.

For temporal segmentation, once the series of maps (1966 - 1979) has been digitized then the variability of runoff for each pixel can be estimated and those pixels with high variability can be identified.

The relational descriptions could be studied by estimating runoff using only meteorologic data. Values of precipitation and temperatures could be taken for the meteorologic stations in each pixel. At first, simple mean values could be used to estimate the temperature and precipitation over a pixel. Evaporation would be estimated from Turc's formula and runoff from the difference between precipitation and evaporation. As some precipitation would be in the form of snow, annual values of runoff, ie. runoff over a calendar year may not be as worthwhile as water year runoff as a response to be modelled. But modelling would indicate some relational indication of modelled and measured runoff, ie. runoff in 90% of the pixels could be estimated to within 20%.

Several pixel sizes should be tried for a runoff map, ie. subdivide the first 1° x 1° pixels into 4, 9 and possibly 16 pixels.

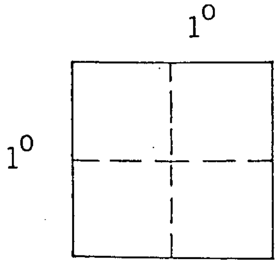


Figure 7

Then resolution dependent information measures, Wong and Vogel (1977), can be applied to examine the change of information with change of pixel size. If the change of information I (over the image) is as shown in Figure 8a, then the pixel size is unimportant, but if the change is as in Figure 8b, then pixel sizes less than t should be used, as there is a sharp decrease in information for pixels larger than t.

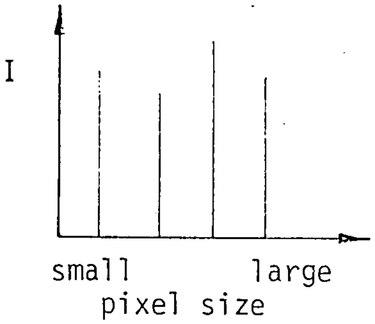


Figure 8a

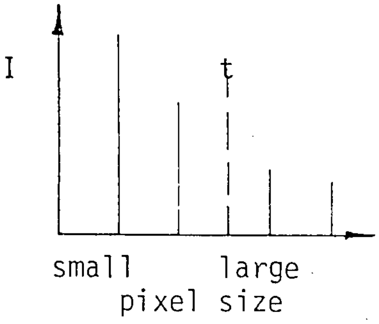


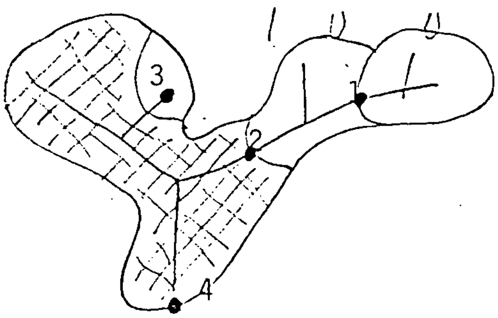
Figure 8b

I is an information measure based upon occurences of certain levels in the image. If all the pixels in an image had the same level, the information content of the image would not change with pixel size, Figure 8a. If the levels change considerably and there are regions of high information content in the image then the situation in 8b holds. The analogy is the blurring of an image as the pixel size increases, Figure 3.

Figure 4 A 512 x 512 image displayed in 256, 128, 64, 8, 4, and 2 levels, respectively.

To produce more flexible and objective digital images of runoff over British Columbia, a set of data showing the relationships of the basins is required. This data set would contain the data necessary to assign runoff to the appropriate areas of the province. This data would involve the boundaries, drainage areas and the linking of the basins. Linking refers to the heirarchial structure, ie. which basins are within which basins. For example in Figure 9, basin 1 contributes to the runoff in basin 2, and basins 2 and 3 to basin 4. The runoffs are measured at points on the stream, gauging stations, which measure the integrated response from the upstream areas.

The runoff assigned to the cross hatched area is runoff at station 4 minus the runoffs at station 2 and 3.



Stations point measure integrated upstream response.

Figure 9

The mean runoff for a pixel has then to be determined from the contributing areas in a pixel. Figure 10 shows 3 contributing basins in the pixel.

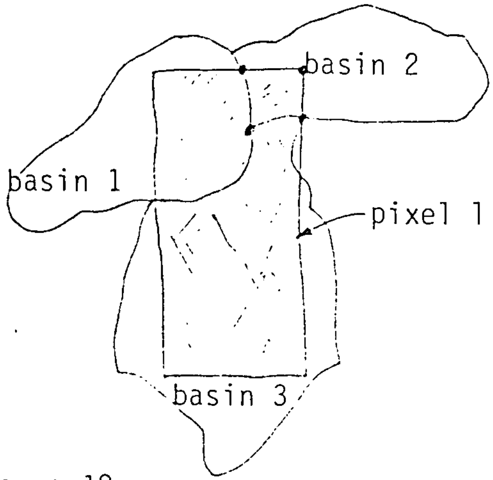


Figure 10

The runoff for a pixel would be the weighted mean, with weights determined by basin areas in the pixel. Once the basin file was established, the effects of altering pixel size could be studied as could the effects of different periods, ie. water year runoffs.

3. INTEGRATION WITH OTHER STUDIES

The file of basin boundaries is required for extraction of physiographic parameters from the 2 km x 2 km bank. This file would be incorporated in the data bank and its development would benefit both the data bank and runoff studies.

Once the basin file is established, gauging strategy could be examined. For example, all gauged basins less than 500 km^2 could be removed from the analysis and the effects on the delineation of hydrologic regions and temporal variability could be assessed, ie. the effect of sensor resolution could be studied.

Also, the question of guaging in terms of level of response could be investigated. In other words, there are more gauging stations required to specify the level of a low flow year to some accuracy criteria, than are required for a high flow year.

With the basin file and the physiographic data bank, estimates of precipitation could be made using physiographic data and these estimates could be tested as predictions for runoff.

Satellite data (GOES) is available for the southern part of the province. This data has shown capability to produce estimates of runoff, Leith (1983). Incorporation of this data into the runoff study could aid in the examination of the capabilities of satellite data.

Once these data sources have been brought together, further examination of the information transfer of various components of the integrated data network may be examined by methods developed by Caselton and Husain (1980). This would allow assessment of the information bearing segments of the network as well as information bearing locations, hydrometric stations or basins within the network.

Recommendations - Certain parts of the study can be started immediately and require no large commitment of resources; in light of the potentially valuable results from the study, these should be undertaken.

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