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QUANTITATIVE GEOMORPHOLOGY OF DRAINAGE BASINS RELATED TO FISH PRODUCTION

By

G. L. Ziemer

STATE OF ALASKA

William A. Egan - Governor

DEPARTMENT OF FISH AND GAME

James W. Brooks, Commissioner

Subport Building, Juneau 99801

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By

G.L. Ziemer, P.E.
Chief Engineer
Alaska Department of Fish and Game
Juneau, Alaska

ABSTRACT

This report covers the results of a study investigating the possibility of developing a classification index system for watersheds which would quantify their total composite salmon production potential. The premise was tested that, within a geologically and climatologically homogenous region, the water flow regimen of streams, and the channels that flow builds, is universally related to certain identifiable characteristics of their basins and drainages and that these control or indicate the level of fisheries production.

This study shows that a correlation between drainage system geometry and freshwater production factors for anadromous fishes can be shown, and an index expressing that relationship, in the case of pink salmon in Prince William Sound, has been developed.

INTRODUCTION

As anadromous fisheries management proceeds from the basic position of husbandry of the existing stocks to the addition of programs designed to increase the quantity and to enhance the quality of the freshwater environment for fish production, it becomes desirable to provide to the manager better tools to equate one site against another so his projects return the maximum dividends. Value judgments to equate the variables and to estimate possible effects upon the whole spectrum of resources is hardly enough and a more rational and definitive approach to evaluation of the inter-related management options is required.

Granted adequate brood stocks to seed the spawning gravels the most significant direct variable in the freshwater salmon environment becomes the water regimen within the waterway. This regimen has both quantitative and qualitative vectors. Seasonal variations of several factors become commanding and even lethal beyond certain limits. Stream flow is importantly influenced or totally controlled by the watershed from which it issues. In its whole dimensions a watershed's identifiable variables, most of which can be measured at least to some degree, include: (1) the climate zone in which it is located, its orientation, exposure, elevations and shape; (2) its drainage system, yield, density, order, slope, competence, and ponding; (3) its ground cover, ice fields, alpine meadows, muskegs, timber, logging cutover, stream canopy, and raw soil exposure; and, finally, (4) its channels including the bed, cross-section, gradient, and stability which provide the fish transport, spawning, incubation and rearing environmental factors. These variables can be included in an analog model. However, such a model may be altogether too complex for effective use and requires fragmentation to find simple handles one can grasp. A competent quantified input may yield an index of the productive potential of the drainage basin. It is toward these goals that this work is directed.

In the preface to his Handbook of Applied Hydrology, Ven Te Chow, the editor, makes the observation "As hydrology is not an exact science, application of hydrologic knowledge to practical problems requires a great deal of rich experience and sound judgment of the hydrologist". The same can be said of anadromous fisheries managers. Hydrologists have developed through their applied research fundamental relationships and emperical formulae sufficiently exact to solve many of their problems quantitatively. Certainly biologists and hydrologists working together will come much nearer to accurately assessing the total fisheries potential than will either working alone.

GEOMORPHIC ELEMENTS

Of fundamental importance is the concept of the drainage basin as an <u>open system</u> tending to achieve a <u>steady state</u> of operation. This open system imports and exports matter and energy through the system boundaries and must transform energy uniformly to maintain operation. The steady state manifests itself in the development of certain topographical characteristics which achieve a time-independent state. Readjustments occur, however, over very long periods of time and geometric forms will show a slow evolution.

The fundamental dimensions of space, mass and time, whether used singly or combined, suffice to define all geometrical and mechanical properties of a drainage basin. Geometric similarity is an important concept of dimensional analysis applied to drainage basins. Systematic description of the geometry of a drainage basin and its stream channel system requires measurement of: (1) linear aspects of the drainage network, (2) areal aspects of the drainage basin, and (3) relief aspects of channel network and contributing ground slopes. Although not entirely free from inconsistencies, this plan of morphometric analysis is operationally useful. (See Appendix A for discussion of geomorphic elements.)

The description of drainage basins and channel networks has been transformed from a purely qualitative and deductive study to a rigorous quantitative science capable of providing hydrologists with numerical data of practical value. Emphasis is upon the geometry itself, rather than upon the dynamic processes of erosion and transportation which shape and control the forms. Applications of principles of mathematical statistics to quantitative geomorphology is essential if meaningful conclusions are to be reached.

Stream channels have finite depths, widths and grades that change systematically as followed downstream and the quantity of discharge increases. The geometry of streams relates width, depth, cross-sectional area, and form to such factors as distance, gradient, discharge and load. The physical sizing of the channel section together with the movement, sorting and placement of the bed materials are the systemic result of a compendium of forces which have been at work over a long period of time, all being inter-related and inter-dependent. Any one, or at most only a very few, of the individual forces, and its own specific measurable quantum index, should be useful as a monitor of the system once a steady state has been achieved and is thereafter maintained. Stream channels--and that includes the fisheries production in them--are not a capricious happenstance, randomly proliferated but are the result of a complex system rather rigid and universal in its functioning.

A statement of basic relationships which has since become known as Playfair's Classic Law of Streams was composed by him in 1802--"Every river appears to consist of a main trunk, fed from a variety of branches, each channel running in a valley proportioned to its size, and all of them together forming a system of valleys connecting with one another, and having such a nice adjustment of their declivities that none of them join the principal valley either on too high or too low a level; a circumstance which would be infinitely improbable if each of these valleys were not the work of the stream which flows in it."--and the scientists ever since have continued to define and relate the infinitely improbable circumstances.

Students of quantitative geomorphology of drainage basins have applied statistical methods of correlation and regression to observational data on basin elements, and have related one or more of the geometric elements of the basins empirically to several independent variables. For a given intensity of the erosion process, conditions for a steady state within a drainage basin are such that values of local relief, slope, and drainage density reach a time-independent steady state in which basin geometry is so adjusted as to transmit through the system just that quantity of runoff water and debris (silt, sand and gravel) characteristically produced under the controlling climatic regime. Such a steady state basin can be expected to accommodate a determinable capacity of anadromous fish spawners through the sorting, grading and placement of channel bed gravels and the runoff water regimen with which those gravels are flushed. Further, the steady state can be expected to continue and the fish capacity maintained unless the intensity of the erosion process is changed (such as may occur, for example, when the land surface is denuded of its vegetative cover through logging of a forested basin) either through increase in runoff intensity or surface susceptibility to erosion or both, whereupon the basin geometry (and the fisheries capacity) is altered. Eventually, when transformation has been completed in adjustment to the altered cover condition, a new set of drainage basin forms will replace the original. In the adjustment period fisheries capacity, most probably, will be significantly affected.

OBJECTIVES

The objective of this study was to develop a numerical figure expressing comparative values for the regimen of freshwater streams favorable to pink salmon production in order to develop a classification index system for watersheds which would quantify their total composite salmon production potential, and constructed on the premise that the water flow regimen of streams and the channels that flow builds, in a geologically and climatologically homogenous region, is universally related to certain identifiable characteristics of their basins and drainages.

METHODOLOGY

The genesis of the concept that the same elements and forces which controlled the geometry of the stream channels also directly controlled the environmental factors necessary for the freshwater production of anadromous fishes occurred during the prosecution of rehabilitation works on the tectonically damaged channel systems of Prince William Sound and particularly those on Montague Island (Anadromous Fish Act, P.L. 89-304, Project No. AFC-3). The March 1964 Alaska earthquake produced some monstrous vertical adjustments in the topography of Prince William Sound with a measured maximum uplift of 38 feet on Montague Island (Geological Survey Professional Paper 546). Subsidence occurred in other regions but of lesser amounts (7-1/2 feet maximum). Horizontal deformation also occurred. Nature in her quest of absolute order and equilibrium proceeded at once to adjust her elements to these newly altered controls. The very magnitude of the vertical deformation unleashed forces which caused aggradation and degradation to proceed at visual rates with changes occurring in years which otherwise would hardly have happened in the time span of centuries. The processes of channel building and the movement, sorting and placement of bed materials took place literally as one watched. That the water, gravels and fishes were all part of the same equation was apparent.

The study to date has been limited to small watersheds covering not more than 10 square miles and free of significant impondments. The fish rearing factors have been excluded by concentrating on those basins supporting pink salmon (Oncorhynchus gorbuscha), which go directly to sea after emergence. By narrowing the initial scope of the effort, it was hoped to increase chances for success. Other aspects and greater scope can be subsequently pursued should positive results be achieved on the first objectives.

The very limited funding for the project required that the input data be extracted from U.S. Geological Survey topographical quadrangle sheets and available aerial photos. More refined input data should produce results of higher confidence and work will continue in further development of the index for Prince William Sound pink salmon streams and, in time, proving up the technique for other geographical regions and for other species.

A model may be set up defining those major items to be tested. Such a model for the study in point is included, as Figure 1, which reflects items tested within this study plus some to be examined through future project expansion or by others working on correlative facets such as temperature regimens.

Standard techniques were employed to measure lineal and areal data and to determine averages and means.

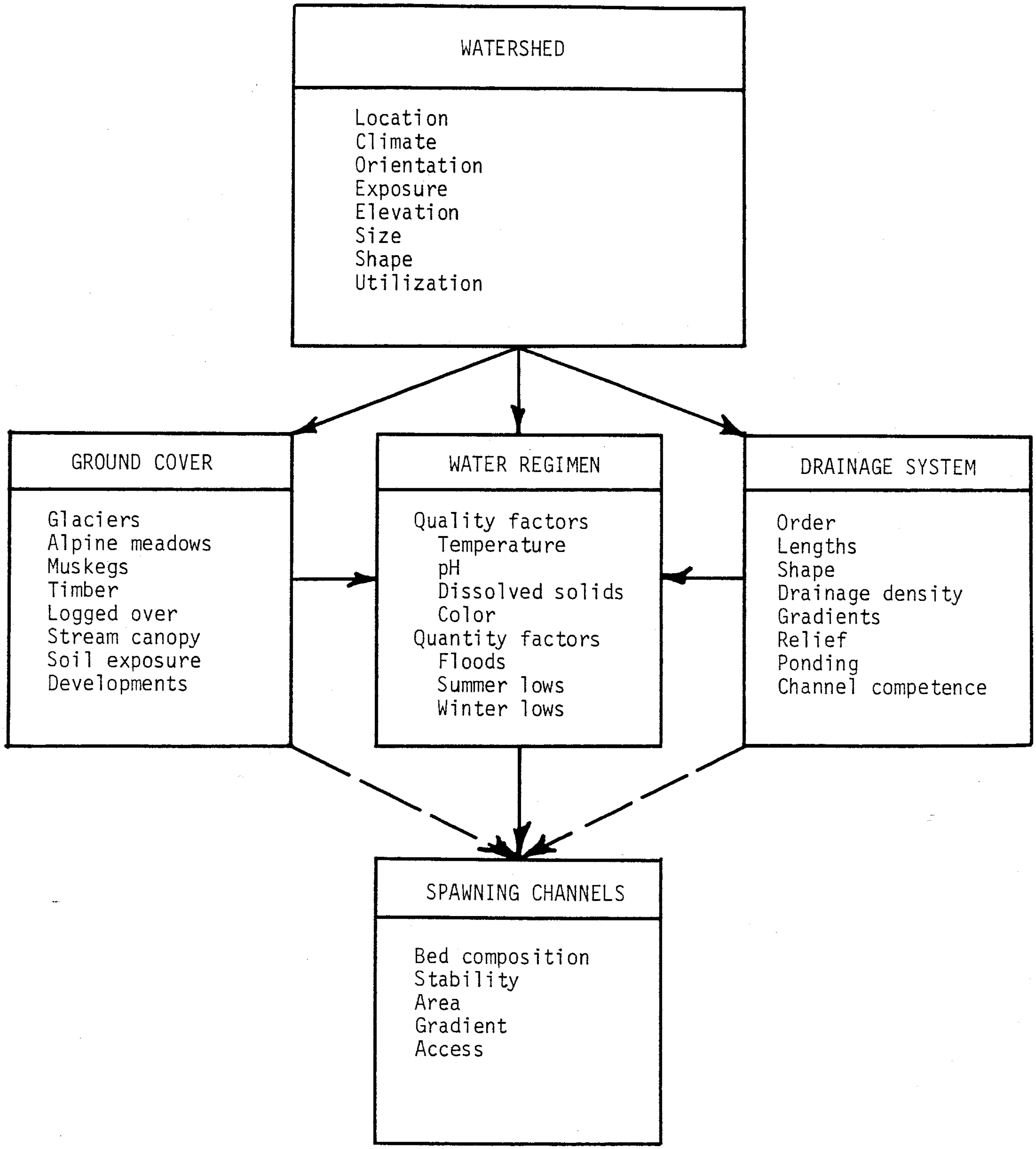
In this report, L_t is the total length of drainage channel in the basin, in miles, and includes all drainage channels large enough to be shown on topographic maps; L_t divided by the drainage area A, in square miles, is defined as the drainage density D_d, given in miles per square mile; $\overline{L}$ is the mean basin length, in miles; and $\overline{S}$ is the mean basin slope. These latter two quantities are determined as follows, using topographic maps of the area:

1) On the topographic map delineate the drainage area above the channel point of high tide influence.

2) Locate the points where contour lines cross the main channel.

3) Planimeter the area within the watershed below each contour line, using significant elevation (θ) intervals.

Figure 1. Model of Program Variables.



4) Measure the distance along the channel from the high tide point to each contour crossing.

5) Prepare a curve showing the relationship between length along the main channel to a contour and the total area under the contour.

6) Prepare a curve showing the relationship between elevation of contour above sea level to the total area under the contour.

7) Both the curves described in numbers 5 and 6 should represent an accumulation of area in an upstream direction, as shown in Figure 4.

8) The area under the length-area curve divided by the total drainage area gives mean basin length $\overline{L}$.

9) The area under the elevation-area curve divided by the total drainage area gives $\overline{H}$, the mean basin rise.

10) $\overline{H}$ in feet divided by $\overline{L}$ in feet gives mean basin slope $\overline{S}$.

Hanning Creek and watershed, ADF&G Stream Catalogue No. 710, on Montague Island, Prince William Sound, Alaska, will serve as the example. The planimetered basin boundaries indicate the area to be 6.27 square miles. The total length of channels identifiable as such on the topo quad sheet, supplemented by aerial photos, is 12.7 miles. It is a 4th order stream (Appendix A). The channel system is shown on Figure 2. The mean basin elevation is 850 feet (Figure 3). The length-area relationships are plotted in Figure 4. The area under the length-area curve by planimeter is 12.28 square inches, and that under the elevation-area curve is 10.06 square inches. The main channel is 2.9 miles long.

$$D_d = \frac{12.7}{6.27} = 2.02 \text{ miles per square mile.}$$

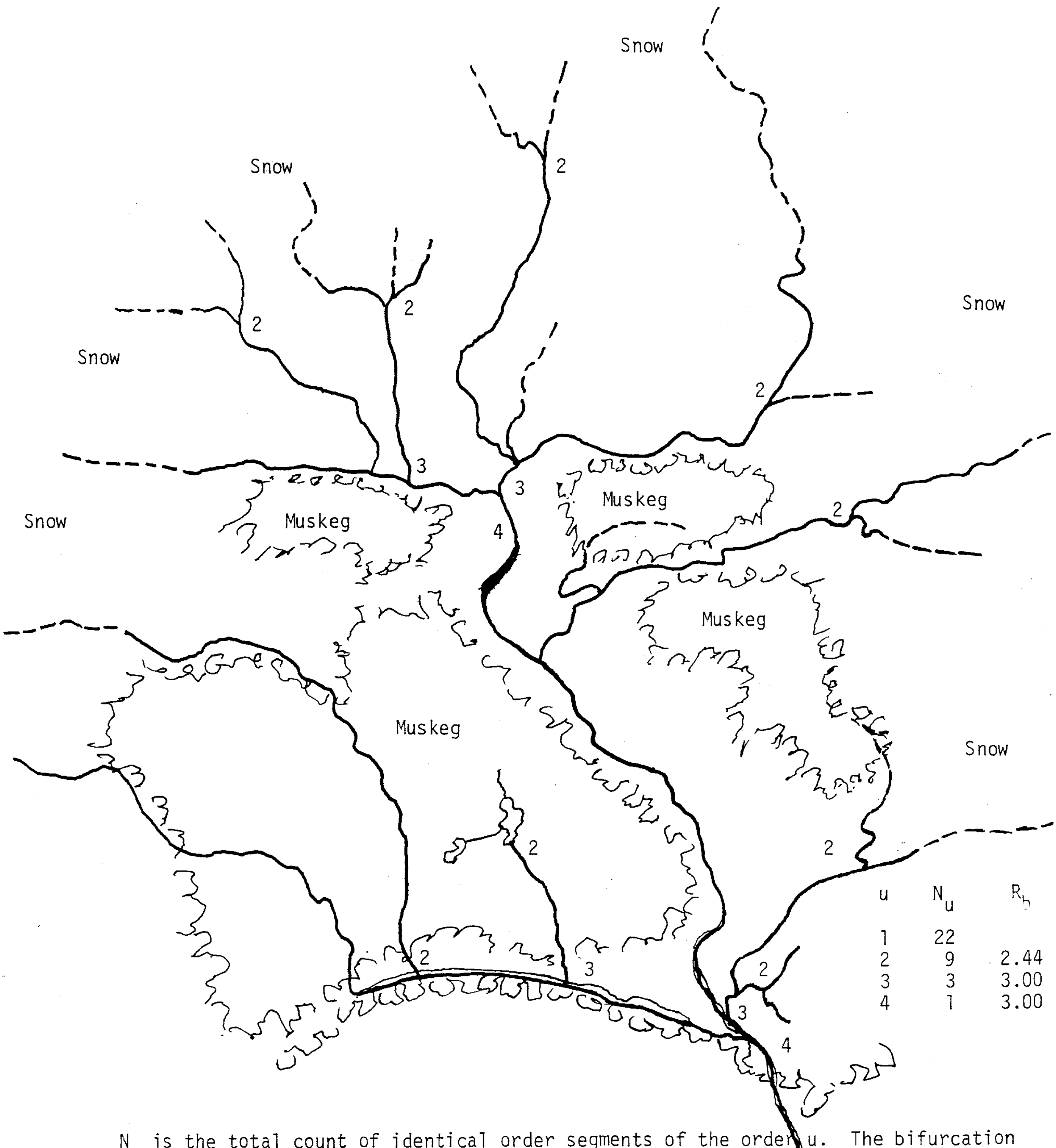
$$\overline{L} = \frac{12.28}{6.27} = 1.96 \text{ miles} = 10{,}349 \text{ feet}$$

$$\overline{H} = \frac{(10.06)}{(6.27)}(500) = 800 \text{ feet}$$

$$\overline{S} = \frac{800}{10{,}349} = 0.077$$

Escapement numbers of pink salmon spawners, as reported by department management biologists are employed in this study as measures of pro-

FIGURE 2. DRAINAGE SYSTEM - TYPICAL



u	N_u	R_b
1	22	
2	9	2.44
3	3	3.00
4	1	3.00

N_u is the total count of identical order segments of the order u. The bifurcation ratio $R_b = \frac{N_u}{N_{u+1}}$ (See Appendix A for development of these values).

FIGURE 3. MEAN ELEVATIONS

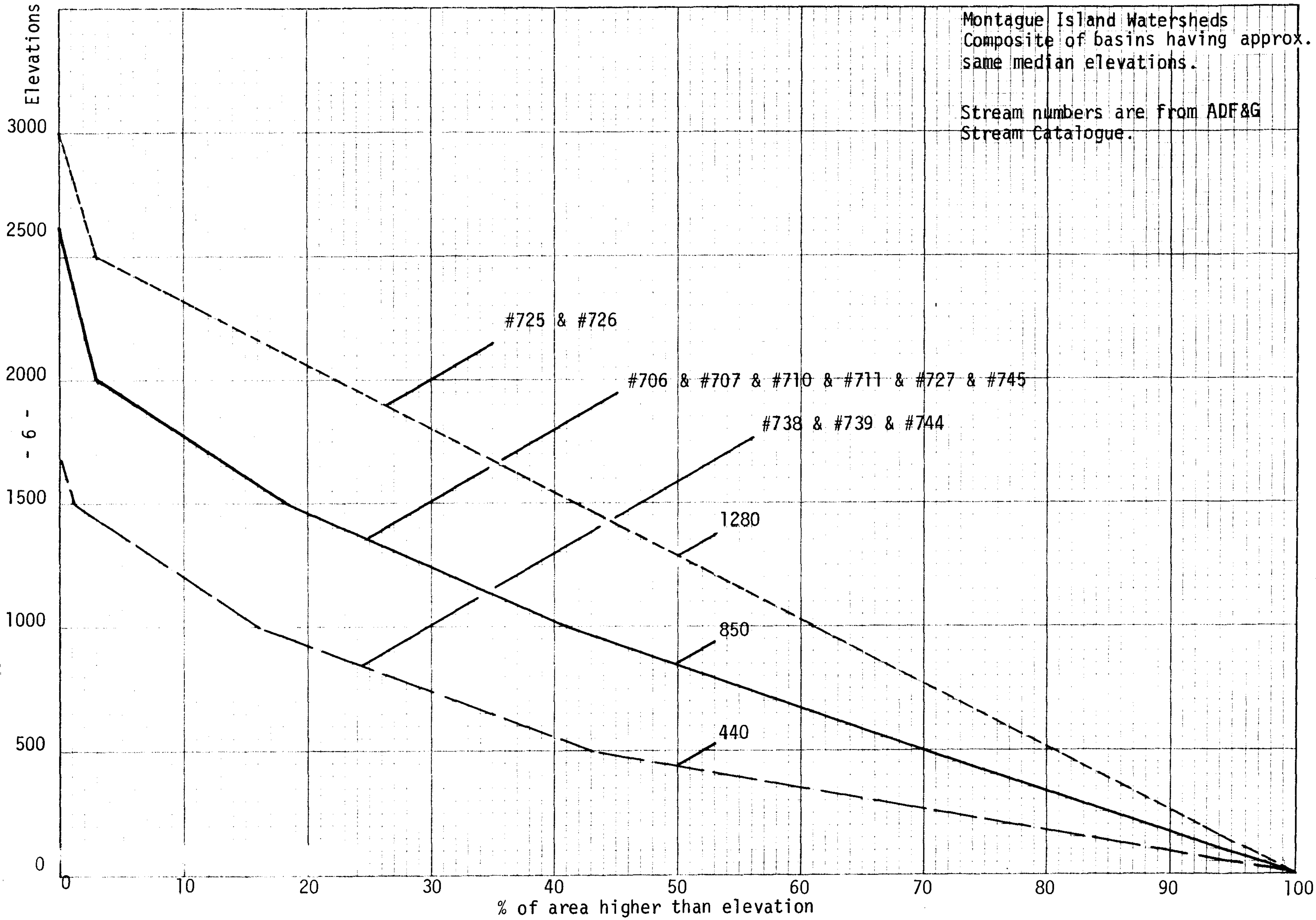
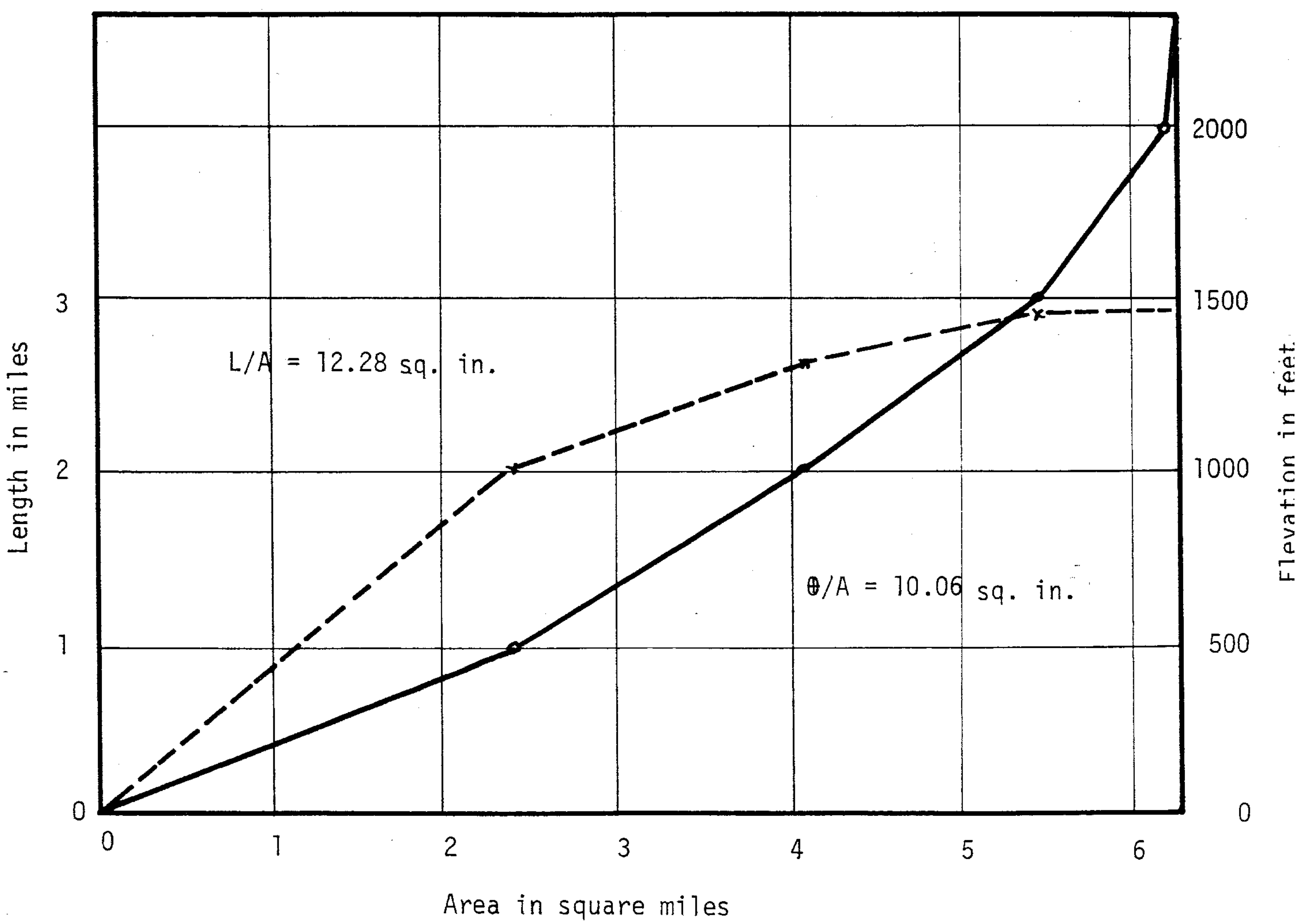


FIGURE 4. LENGTH - HEIGHT RELATIONSHIP
TYPICAL

θ	L	A
0	0	0
500	2.0	2.40
1000	2.6	4.08
1500	2.9	5.45
2000	2.9	6.25
2320	2.9	6.27

θ denotes elevation; L equals length of channel to denoted elevation and A is the total area under the elevation within the drainage basin.



ductivity. See Appendix B for methodology.

SUMMARY

The Montague Island drainage basins studied fell generally into three characteristic elevation groupings of median basin elevation. The percentage of the area of the basin higher than the elevation was plotted against the elevation to establish the height configuration and the 50 percentile point. No correlation could be discerned with other variables in this limited work. The median elevation classes were found to be 440, 850, and 1,280 feet. Figure 3 delineates the basic elevation patterns.

The drainage system networks derivation required the use of U.S. Forest Service aerials to supplement U.S. Geological Survey topographical quadrangle sheets. No detailed on-the-ground field surveys were made for this study, but such field surveys may be desirable in future efforts to standardize the essential input data to be secured from them. However, one of the basic concepts was (and is) utilization of existing data for needs of economy, and attempts must continue to exploit these data sources, with watershed surveys included only to test the validity of these reference materials. There are preliminary observations that some first-order waterways do not appear on the U.S.G.S. topo sheets and, also, that there is considerable variability in the cardiography within a limited region.

The drainage factors are summarized in Table 1 and the basin factors are given in Table 2. These constitute the variables between watersheds tested for significance and correlation with fishery production.

Run-off in its several dimensions is a major building force in the geometry of channels and was examined intensively for effects upon fishery production (see Appendix B for measures). Research on the temperature regimen of streams is being pursued by others. Some beginning work on low-flow cataloguing has been done, but this should be the subject of a separate and further study apart from this program, at least at this time. In the investigations of the various combinations of watershed properties, it was found that a basin factor K could be described which included most of the significant drainage basin characteristics affecting the run-off process, which at the same time provided the best correlation with the key hydrograph parameters of the peak discharge and time to peak (Eagleson). Channel capacity is superior to basin area as an indicator of mean flow and shows less pronounced differences among the basins (Brown). The factor $K = \frac{L_t \bar{L}}{\bar{S}^{0.5}}$ (Eagleson) showed fair correla-

TABLE 1. DRAINAGE FACTORS

STREAM		DRAINAGE SYSTEM FACTORS				
Name	No.	L_t	D_d	$\overline{L}$	$\overline{H}$	$\overline{S}$
Humpy	11	7.5	1.74	3.30	1460	0.0912
Control	52	4.9	1.06	2.62	1145	0.0827
Lagoon	99	6.7	1.41	3.48	1630	0.0887
Indian	117	11.4	1.97	2.47	1580	0.1211
Pigot-North	430	1.5	1.34	1.18	1035	0.1661
Pigot-South	432	7.6	3.30	2.29	1265	0.1046
Paulson	445	2.5	1.49	1.77	825	0.088
Mink	480	3.0	1.13	2.20	1070	0.0921
MacLeod	706&7	10.2	1.33	2.78	975	0.066
Hanning	710	12.7	2.02	1.96	800	0.077
Quadra	711	12.2	1.59	2.80	855	0.057
Montague	729	4.1	1.66	1.60	842	0.099
Russel	738	(2.8)	(2.59)	1.49	594	0.075
Swamp	739	(2.0)	(2.04)	1.22	500	0.079
Wilby	744	1.9	1.61	1.15	712	0.117
Wild	745	2.7	1.20	1.58	982	0.118
Shad	749	5.2	2.41	1.81	425	0.0444
Udall	770	3.8	1.41	1.94	1145	0.112
Pautzke	775	6.1	2.03	2.48	790	0.0603
Dog Salmon	806	6.5	2.60	1.72	865	0.0952
Etches	811	4.6	1.46	1.70	835	0.0930
Nuchek	812	11.3	2.18	2.49	515	0.0390
Constantine	815	13.8	1.70	3.85	835	0.0411
Anderson	828	5.6	1.41	3.33	650	0.0369
Canoe	850	2.2	1.00	1.70	520	0.0579

L_t is total channel length in miles; D_d is the drainage in miles per square mile; $\overline{L}$ is the mean basin length in miles; $\overline{H}$ is the mean basin rise in feet; and $\overline{S}$ is the slope derived by dividing $\overline{H}$ by $\overline{L}$ in feet.

TABLE 2. BASIN FACTORS

STREAM		CLASSIFICATIONS			INDICES		
Name	No.	Area	Elev.	Order	R_b	K	Z
Humpy	11	4.32	1400	4	2.70	82	63
Control	52	4.62	1000	3	2.80	45	34
Lagoon	99	4.76	1610	4	3.00	78	55
Indian	117	5.78	1275	3	3.17	81	40
Pigot-North	430	1.12	750	3	4.25	6	10
Pigot-South	432	2.30	1340	4	2.86	54	72
Paulson	455	1.68	700	-	--	15	30
Mink	480	2.65	1050	3	4.00	22	27
MacLeod	706&7	7.65	850	4	2.67	110	56
Hanning	710	6.27	850	4	2.44	89	51
Quadra	711	7.67	800	4	4.00	143	78
Montague	729	2.47	750	3	2.50	21	27
Russel	738	1.06	450	3	2.40	--	51
Swamp	739	0.98	425	4	2.60	--	31
Wilby	744	1.18	450	2	3.00	7	16
Wild	745	2.24	925	3	2.50	13	16
Shad	749	2.15	425	4	2.83	45	98
Udall	770	2.68	1125	3	3.00	23	24
Pautzke	775	3.00	750	3	3.75	62	83
Dog Salmon	806	2.50	825	4	3.11	36	47
Etches	811	3.13	800	3	3.50	26	27
Nuchek	812	5.19	475	4	2.67	142	139
Constantine	815	8.13	760	4	3.82	262	159
Anderson	828	3.98	475	-	--	94	127
Canoe	850	2.19	480	-	--	15	29

The area of the watershed is in square miles; the mean elevation of the watershed was established as outlined for construction of Figure 3; order and ratio of bifurcation (R_b) of streams are non-dimensional characteristics; K and Z are index factors calculated from the above designated data.

tion with fish production for very localized areas, but failed as an acceptable predictor for regional streams.

The localized area correlation of the factor K to fish production indicated the direction to be probed for more significant results. A thorough working of the data produced the index $Z = \frac{D_d \bar{L}}{S}$ for pink salmon production in Prince William Sound which shows acceptable correlation and provides an operational base on which to proceed on this project in the future. The correlation between productivity and the index number is presented in Figure 5. The base line is plotted at the 400 Z-units level with guide limits at 50 percent plus and minus. The data is summarized in Table 3.

Appreciable divergence occurs in five of the twenty-five streams and of these five, three are ascribable to identifiable causative agents. Humpy Creek is blocked by a waterfall less than 200 yards above the mouth and fish access is stopped at that point. Russel Creek contained a jungle of logs and logging debris, including blocked fish access just above the high-tide line, all of which affected its production. Meacham Creek (Pigot Bay, North side, #430) is atypical in that this small drainage basin is served by an outlet stream which occupies at a lower elevation for considerable distance (over 1/2 mile) the outwash delta of a large stream and thereby benefits from a warm water (during the winter season when incubating eggs are in the gravels) accretion flow from ground-water sources. The reasons for the anomalies in Shad and Anderson creeks data have not been determined. The minor variations noted at four streams may be due to any number of undefined reasons including poor data input.

CONCLUSIONS

Index numbers closely alike indicate streams of comparable hydrological characteristics affecting pink salmon production provided the limitations set out hereinbefore are satisfied. The greater the index number, the higher the productivity of the stream should be. The potential spawning capacities of the several streams have been calculated on that basis.

A correlation between drainage system geometry and freshwater production factors for anadromous fishes can be shown, and an index expressing that relationship, in the case of pink salmon in Prince William Sound, has been developed. An index of the salmon production potential of freshwater streams quantitatively forecasting the number of spawners a stream system can accommodate is possible and, as a management tool, will help the biologists in determining optimum spawning escapements for individual stream systems.

FIGURE 5. INDEX NUMBER - PRODUCTIVITY OF PINK SALMON CORRELATION
PRINCE WILLIAM SOUND

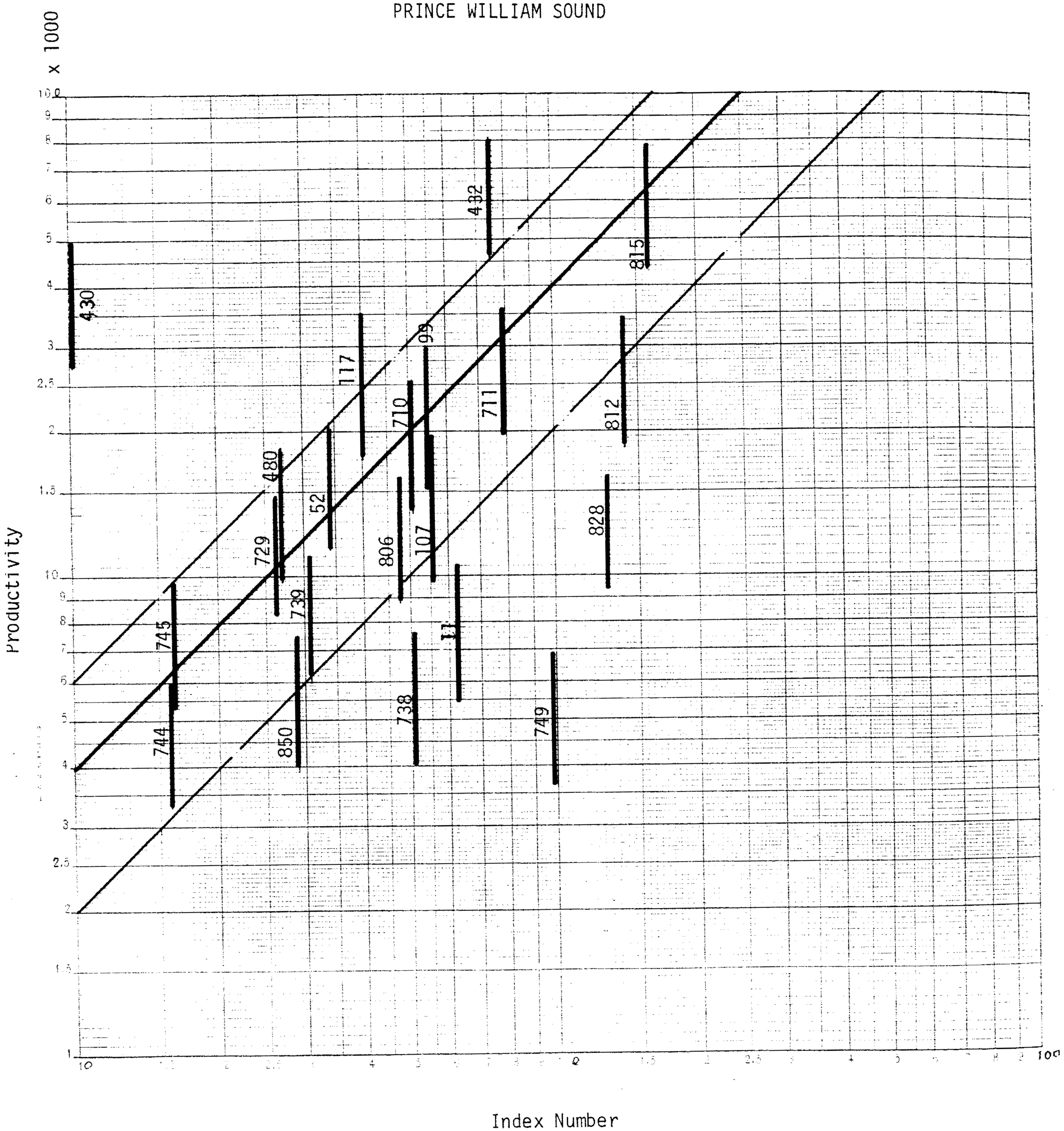


TABLE 3. INDEX OF PINK SALMON CAPACITY - PRINCE WILLIAM SOUND

STREAM Name	STREAM No.	INDEX No.	(1)	Spawning Cap. (±50%) (2)	ESCAPEMENT Standardized Range (3)	
Humpy	11	63	--	25,200	10,100	5,500
Control	52	34		13,600	20,400	11,200
Lagoon	99	55		22,000	29,300	16,100
Indian	117	40		16,000	30,800	17,000
Pigot-North	430	10	++	4,000	48,900	26,900
Pigot-South	432	72	+	28,800	80,200	44,100
Paulson	455	30		12,000	(4)	
Mink	480	27		10,800	17,500	9,700
MacLeod	706&7	56	-	22,400	17,500	9,700
Hanning	710	51		20,400	24,500	13,500
Quadra	711	78		31,200	35,700	19,700
Montague	729	27		10,800	14,700	8,100
Russel	738	51	--	20,400	7,500	4,100
Swamp	739	31		12,400	10,800	6,000
Wilby	744	16		6,400	6,100	3,300
Wild	745	16		6,400	9,600	5,300
Shad	749	98	--	39,200	6,700	3,700
Udall	770	24		9,600	(4)	
Pautzke	775	83		33,200	(4)	
Dog Salmon	806	47		18,800	15,700	8,700
Etches	811	27		10,800	(4)	
Nuchek	812	139	-	55,600	33,400	18,400
Constantine	815	159		63,600	76,500	42,100
Anderson	828	127	--	50,800	15,900	8,700
Canoe	850	29	-	11,600	7,100	3,900

Note: Applies to pink salmon only

(1) Degree of divergence between calculated capacity for spawners and escapement reported for 5 yr. pre-earthquake period, ++ and -- indicating major, and + and - indicating significant divergence.

(2) Calculated capacity for spawners on basis of Z Index Number X 400.

(3) Reported escapement for 5 yr. pre-earthquake period reduced to standardized range.

(4) Escapement data not at-hand.

The preliminary work carried on to date indicates full justification for continuing the research effort. The next item of study must work finite channel and drainage system data against proper fish production data through regression analysis. Transferability regionally must be tested as well as application to species other than pink salmon.

REFERENCES

Behlke, C.E. 1957. The mechanics of overland flow. Ph.D. Thesis. Stanford Univ.

Blench, T. 1971. Morphometric changes. Symposium on river ecology and the impact of man. MS. Univ. of Massachusetts.

Brown, D.A. 1971. Stream channels and flow relations. J. Water Resources Research. Vol. 7, No. 2.

Chow, V.T. 1964. Preface, p. ix-x. In V.T. Chow, (ed.), Handbook of applied hydrology--a compendium of water-resources technology. McGraw-Hill Book Co., New York.

Rantz, S.E. 1964. Stream hydrology related to the optimum discharge for king salmon spawning in the northern California coast ranges. Geological Survey Water-supply Paper. p. 1779-AA.

Strahler, A.N. 1964. Quantitative geomorphology of drainage basins and channel networks, Sec. 4, p. 39-76. In V.T. Chow, (ed.), Handbook of applied hydrology--a compendium of water-resources technology. McGraw-Hill Book Co., New York.

APPENDIX A. GEOMORPHIC ELEMENTS

Systematic description of the geometry of a drainage basin and its stream channel system requires measurement of the linear aspects of the drainage network, the areal aspects of the drainage basin, and the relief aspects of the channel network and contributing ground slopes. Each element is only briefly discussed and those readers requiring greater detail are referred to any of the standard texts available on quantitative geomorphology of drainage basins and channel networks.

I. Linear Aspects of the Channel System.

A. Stream Orders. Usefulness of the stream-order system depends on the premise that, on the average, if a sufficiently large sample is treated, order number is directly proportional to size of the contributing watershed, to channel dimensions, and to stream discharge at that place in the system (Strahler). The stream order number is dimensionless.

In the hypothetical basins of Figure A, the stream segments have their order numbers indicated by the figures 1-2-3-4. Basin A supports a 4th order and B and C, 2nd order streams. The total count of identical order segments yield the number (N_u) of segments of the order (u).

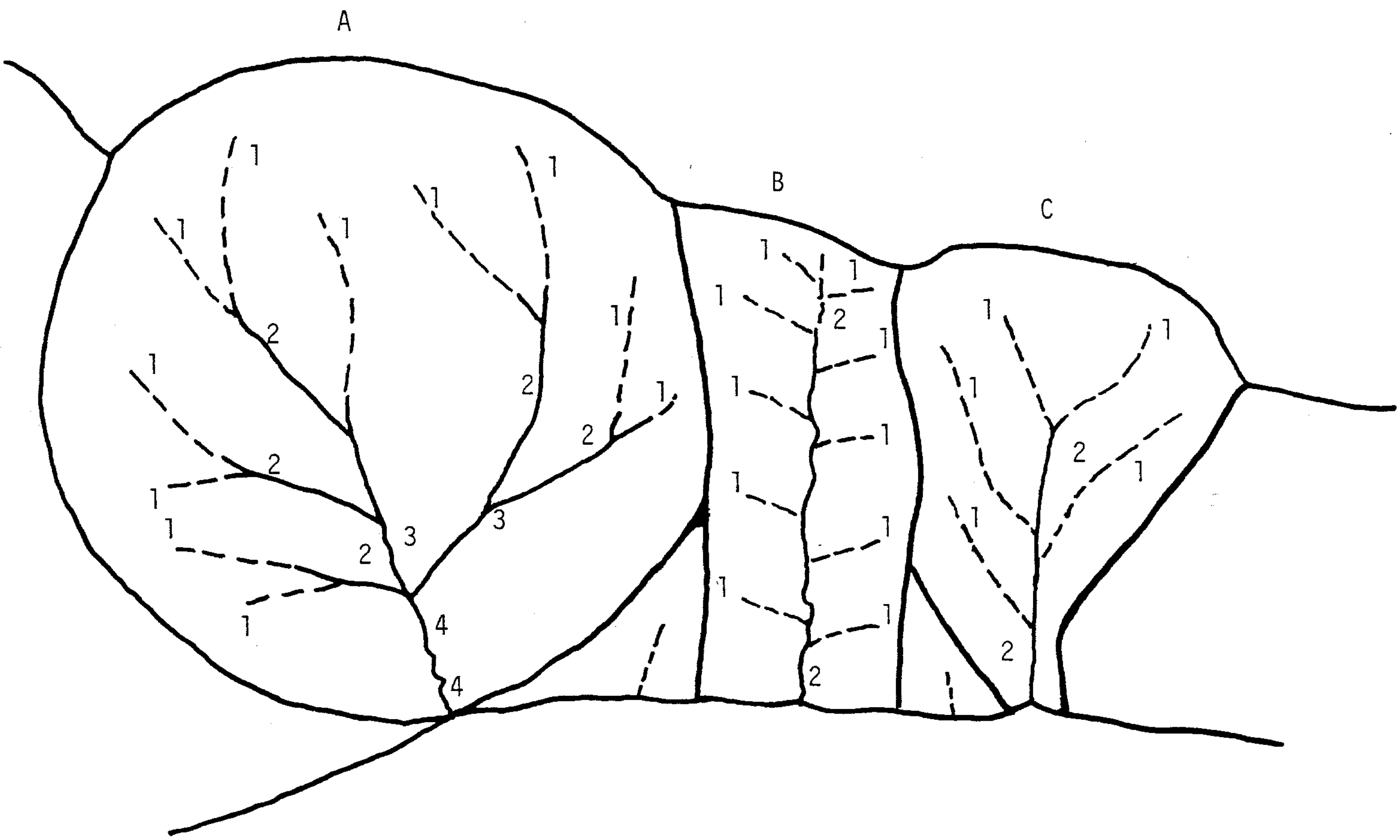
The bifurcation ratio (R_b), the term for the ratio of the number of segments of a given order (N_u), to the number of segments of the next higher order ($N_u + 1$), is important in systems comparisons. Using the above figures and data, the bifurcation ratio of class 1 to 2 streams for Basin A is 2.2, for B is 11.0 and for C is 5.0. An average value can be calculated for a given drainage system by using regression techniques.

These are useful tools in classifying and sorting systems for homogeneity when developing or applying index criteria.

B. Stream Lengths. Mean length $\overline{L}_u$ of a stream-channel segment of order u is a dimensional property revealing the characteristic size of components of a drainage network and its contributing basin surface. The first-order stream channel with its contributing first-order drainage-basin

FIGURE A.   STREAM ORDERS

Order Number u	Basin A	Basin B	Basin C
	Number of Streams N_u		
1	11	11	5
2	5	1	1
3	2	0	0
4	1		
5	0		



surface area should be regarded as the unit cell, or building block, of any watershed. Because first-order drainage basins tend to be geometrically similar over a wide range of sizes, it matters little what length property is chosen to provide the characteristic measurement of size by which systems are compared from region to region (Strahler). While length of first-order channels is a convenient length measure, it might be equally effective to select another dimensionally valid vector as an alternative index of scale of the unit basin and still satisfy the law of stream lengths. In this work, which seeks (at least in these early stages of research) to develop a fish/stream index using data taken from aerial photos and U.S.G.S. 1/63,360 quadrangle sheets, it became necessary to use the mean basin length ($\bar{L}$) because of the great variation in delineation of the first-order stream channels. It will be easier and more reliable, with the minimum of field surveys under our costly Alaskan mapping situation, to secure input data for the mean basin length determination than for other length measurements.

C. Length of Overland Flow. The length of the overland downslope non-channel flow path from a drainage divide to a point on the adjacent stream channel is one of the important independent variables affecting both the hydrologic and physiographic developments of drainage basins. During the evolution of the drainage system, the length of the overland flow path is adjusted to a magnitude appropriate to the scale of the first order drainage basins and is approximately equal to one-half of the reciprocal of the drainage density (Horton). In regional, mature, steady-state watersheds comparative differences in this variable will be within acceptable limits and adequately compensated through inclusion of the drainage density vector.

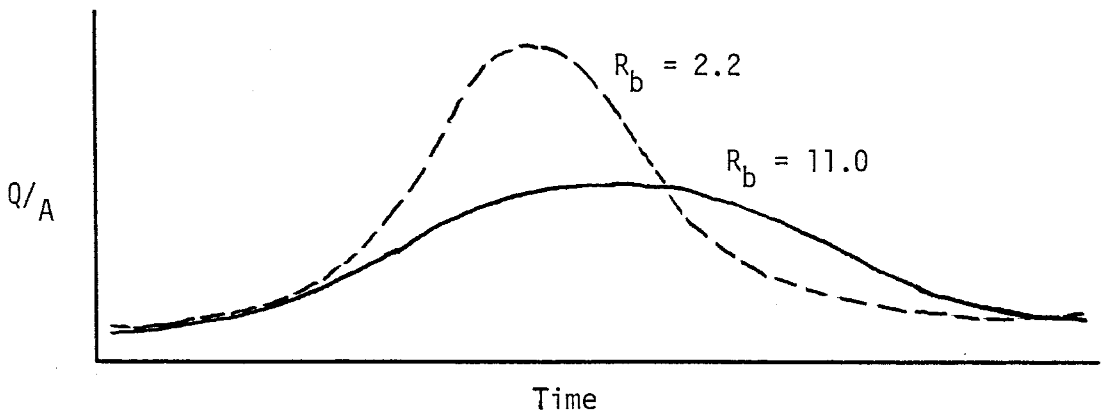
II. Areal Aspects of Drainage Basins.

A. Area to Length. Regionally, within individual stream order classes, it has been found that the absolute stream length L relates to an exponential function of the area A as $L = cA^x$.

B. Area to Discharge. A measure of the rate of basin discharge Q, such as the mean annual flood, relates to area A, as expressed in the empirical equation $Q = kA^y$ with the variables taking on constant values within stream order classes within a region.

C. Basin Shape. Various methods of expressing basin shape have been used to include the shape effect upon stream discharge characteristics, including circularity (ratio of basin area to the area of a circle having the same perimeter as the basin), and elongation (diameter of a circle of the same area to the maximum basin length). These expressions of rotundity generally are intended to account for the effects of bifurcation. Long narrow basins with high bifurcation ratios would be expected to have drawn out flood-discharge periods, whereas rotund basins of low bifurcation ratio would tend to peak sharply. The bifurcation ratios of Figure A could be expected to produce schematic hydrographs shown on Figure B.

FIGURE B. SCHEMATIC HYDROGRAPHS



The effectiveness of the measures of basin outline form as factors in the hydrology of a watershed have been tested (Morisawa) and found short on mathematical dependability. From this it has been concluded (Strahler) that controls other than drainage basin outline form dominate the hydrologic characteristics of a basin.

D. Drainage Density. The ratio of total channel segment lengths cumulated for all orders within a drainage basin to the total basin area is termed the drainage density of the basin. It is normally expressed in miles per square mile. It is a very important indicator of the lineal scale of land-form elements in stream constructed topography (Horton). In general, low drainage density is favored in regions of highly resistant or highly permeable subsoil materials, under dense vegetative cover, and where relief is low; high drainage density is favored in regions of weak or impermeable subsurface materials, sparce vegetation, and mountainous relief (Strahler).

The inverse of drainage density as a property has been used by some hydrologists. Termed the 'constant of channel maintenance', it gives the number of square feet of drainage area surface required to sustain one lineal foot of channel.

Channel frequency is the term applied to the number of stream segments per unit area. Two basins may have the same drainage density but different stream frequencies (and conversely). Much testing, covering a vast range in scale, climate, relief, surface cover, and geologic type (Melton), shows that the relationship of density to frequency tends to be conserved as a constant in nature.

III. Relief Aspect of Channel Networks.

A. Channel Gradients. The channel gradient is the function of the elevation and the horizontal distance, as delineated by a longitudinal profile. A single channel profile follows the thalweg of one channel continuously despite the junction of tributaries of equal or of lower stream order. Single-channel profiles of almost all streams, under a wide range of climatic and geologic conditions, show upconcavity, i.e., a persistent downstream decrease in gradient (Strahler). Gilbert's law of declivities states that gradient bears an inverse relation to discharge because, as discharge increases, channel cross-section increases, reducing proportionately the frictional losses of a stream and enabling it to carry its bed-load particles downstream as the lesser gradient suffices for the transport of smaller size bed materials. The longitudinal profile of a stream channel consists of a series of connected segments and, as pointed out by Mackin, each segment has the slope that will provide the velocity required for the transportation of all of the load supplied to it from above, and this slope is maintained without change so long as controlling conditions remain the same. The sediment bed, continuous and fully available for transportation, is always carried to its capacity as a function of the flow. The bedload function gives the equilibrium transport of materials, both in amount and composition, for all discharges for a given channel.

A composite gradient of several adjacent reaches of a stream is often useful. The equivalent main channel slope of the longest watercourse yields a single numerical value of significant characteristics for small basins. I have found it expedient in my work in this basin-fisheries index project to use a gradient vector derived by dividing the mean basin rise by the mean basin length.

B. Basin Relief. The potential energy quotient is indicated by the maximum relief of the basin as measured by the difference in elevation between its high and low points. The rate at which this potential energy is converted into kenetic energy governs the instanteous magnitude of the forces by which the drainage basin sculpture is developed. (The aeolian and tectonic forces and their results are not germane nor included in this work directed toward water-fisheries considerations.) A basin and its drainage system mature and a steady state develops as the summation of all work approaches zero, i.e., the rates of generative conversion and dissipation of energy reach a state of dynamic equilibrium. Such a steady state for a channel is related to a specific (discharge) flow rate and may be fashioned by that rate of discharge which just fills the formal channel to bank-full capacity. Over-bank flows in that situation will upset the essential equilibrium and, if sufficiently large and then continued beyond a critical time period, will create conditions requiring reshaping of the channel configuration.

Relief indices other than maximum may be more appropriate for certain purposes, such as this one, where a composite rather than an extreme value is required. For this project I have found that the mean basin rise (Eagleson) is best suited and most useful despite the tedious process required for its development.

APPENDIX B. MEASURES OF FISH PRODUCTION

The use of the streams on the westerly side of Montague Island as the data base for the exploration of a fish-stream index system was an unplanned happenstance. The possibilities were exposed during the course of another project. The minimum resources required to exploit the ideas and concepts were available and it followed easily to expend the effort necessary to examine the hypothesis. The index item remains an unfunded project and, as such, an extra-curricular activity dependent upon opportunism rather than selective design. One unfortunate aspect of this situation is the necessity to do the site work in an area where there is an absence of a reliable measure of fishery production both in the past and the near future (due to transitional effects of 1964 tectonic deformation).

For this study to date it has been necessary to assume that recorded historical fish production is an acceptable measure of the production potential; that the numbers of spawners utilizing a stream is a proper measure of the fish production in that stream; that the escapement count has been accurately made and is on the same datum, stream to stream and year to year; and, that the effects of the fishery harvest have been equal on all of the stocks. Each tenent of that assumption is open to challenge, but it remains as the only tool available for use. In a formal project statistically significant input could be assured, not assumed.

Examination of the escapement data provided by the Prince William Sound district suggested that some selectivity in its use was desirable. The excessive variability in the numbers and the absence of any data for some years and streams resulted in an attempt to standardize the escapement data. The 5-year period immediately prior to 1964 (to avoid the earthquake effects) was used as the base period. The range in the ratio of escapement counts relating maximum to 5-year average varied from a very close 1.11 to a wide 2.60 with a mean ratio for the twenty streams of 1.58. The range was arbitrarily standardized at $1.00 + \left(\frac{1.58 - 1.00}{2}\right) = 1.29$ for the high escapement and at $1.00 - \left(\frac{1.58 - 1.00}{2}\right) = 0.71$ for the low figure. See Table A for the measures of fishery production used in the project.

TABLE A. PRODUCTION OF PINK SALMON - PRINCE WILLIAM SOUND.

STREAM		ESCAPEMENT				
Name	No.	Maximum	5-year Average	Ratio	Standard	Range
Humpy	11	16,010	7,805	2.05	10,100	5,500
Control	52	31,220	15,800	1.97	20,400	11,200
Lagoon	99	25,320	22,700	1.11	29,300	16,100
Indian	117	27,100	23,950	1.13	30,800	17,000
Pigot-North	430	61,640	37,870	1.62	48,900	26,900
Pigot-South	432	80,360	62,210	1.29	80,200	44,100
Paulson	455	--	--	--	--	--
Mink	480	24,400	13,850	1.79	17,500	9,700
MacLeod	706&7	22,350	13,570	1.65	17,500	9,700
Hanning	710	40,400	18,990	2.12	24,500	13,500
Quadra	711	56,640	27,700	2.04	35,700	19,700
Montague	729	18,000	(11,400)	--	14,700	8,100
Russel	738	15,200	5,840	2.60	7,500	4,100
Swamp	739	15,200	8,436	1.80	10,800	6,000
Wilby	744	7,060	4,720	1.40	6,100	3,300
Wild	745	10,720	7,460	1.43	9,600	5,300
Shad	749	10,200	5,195	1.96	6,700	3,700
Udall	770	--	--	--	--	--
Pautzke	775	--	--	--	--	--
Dog Salmon	806	21,030	12,175	1.72	15,700	8,700
Etches	811	--	--	--	--	--
Nuchek	812	35,490	25,950	1.37	33,400	18,400
Constantine	815	93,550	59,280	1.57	76,500	42,100
Anderson	828	18,690	12,300	1.52	15,900	8,700
Canoe	850	7,020	5,500	1.27	7,100	3,900