

Whitney M. Borland and The Bureau Of Reclamation - 1930 to 1972*

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1. Introduction



Whit Borland's career with the Bureau of Reclamation began in 1930 and in 1972 he retired from the Bureau after distinguishing himself throughout the United States and world in the sedimentation field. Within the Bureau he was known as "Mr. Sediment" in research, planning, construction, and operation and maintenance of irrigation, hydroelectric, and municipal water projects involving sedimentation and river channel hydraulics problems. Whit and the authors of this report had a common background and interest in their chosen engineering profession in sedimentation for the Bureau of Reclamation. All three were born and raised on farms in Colorado, Iowa and North Dakota. They served as Head, Sedimentation Section for the Bureau and enjoyed the opportunity for field reconnaissance and direction of sediment investigations of river channels and storage reservoirs built thereon. In Whit's case his enthusiasm for diagnosis of engineering problems involving sedimentation was well supported by his natural mechanical ability whether it involved taking apart engines for his lawn mower or rebuilding the engine of his automobile.

In Whit's tenure as Head of the Sedimentation Section, many engineers received their basic training (a few of the best remembered), i.e. Carl Miller, Joe Lara, Ken Schroeder, Lou Seavy, Frank Illk, Dale Henry, Jack Sheppard, Gene Jarecki, Nolan Daines, Al Gibbs, Tom Murphy, Dave Gill, Gary Rome, Jim Blanton, Gene Cristofano, Bruce Blanchard, Jerry Buchheim, Bob Madler, Ken Wright, and the authors. Whit co-authored several technical engineering professional papers with colleagues in the Bureau; however, he co-authored and maintained a special and mutual interest in sedimentation research with Emory W. Lane.

This report highlights many of the reports he either authored or co-authored with Bureau colleagues and Sedimentation Section employees in the

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period from 1946 until his retirement in 1972. In the period from 1970 to 1972 he devoted his time primarily to preparation of the two-volume report he authored on the collection of basic data, analyzing and making recommendations for sediment and degradation problems associated with Pa Mong Project on the Mekong River, Thailand and Laos.

Many activities outside of the Bureau of Reclamation interested Whit, as he was an avid and active member of the Colorado Mountain Club enjoying the climbing and skiing. He explored the science and physics of snow movement and pioneered studies on avalanche phenomena and prediction. He consulted on avalanche awareness with the Highway Department in Colorado. As a consultant with personal friendship of former 10th Mountain Division members, he was involved with the avalanche studies for the developers of the ski resort at Vail, Colorado.

After retirement in 1972 Whit became a consultant on a number of different projects. With his expertise on sediment transport and river channel hydraulics his work varied from international projects to working directly on river migration and stability studies for the Bureau of Indian Affairs at their Phoenix Office.

2. Assignments With Usbr Prior To 1942 And Wwii

Whit's educational background included a Bachelors Degree from the University of Nebraska and a Masters Degree from the University of California both in Mechanical Engineering. After starting his professional engineering at the Bureau of Reclamation he obtained a Masters Degree in Civil Engineering from the University of Colorado in 1938. His first assignment in 1930 with the USBR was in the Hydraulic Laboratory at Montrose, Colorado on testing hydraulic models for Imperial, Grand Coulee, and Stewart Mountain Dams. After working in Montrose he worked on the addition to the laboratory on Colorado State University campus followed by working at the hydraulic laboratory part time in the design, construction, and testing of hydraulic models for other Bureau of Reclamation dams. In 1936 he was permanently assigned to the Spillway Design Section in Denver and completed a major undertaking in a study of backwater caused by Grand Coulee Dam on the Columbia River that included channel improvements for decreasing backwater impacts. From this study he prepared a report for International Water and Boundary Commission. Because of his background in computing water surface profiles in the early 1940's on the Columbia River he established a reputation as the Bureau's top hydraulic engineer in river channel hydraulic computations. For years his stack of hand computations, undoubtedly done with a slide rule or the early desktop mechanical calculator, were on file in the Sedimentation Section of the USBR.



Bureau of Reclamation staff at Hydraulic Laboratory, Ft. Collins, Colorado April 1931 (back row) Richard R. Randolph, Emory W. Lane, Virgil C. Hammond, Joseph N. Bradley, Charles W. Thomas, Graydon C. Wright, (front row) Vincent T. Bliss, Robert A. Goodpasture, Walter H. Price, James W. Ball, Richard J. Willson, William O. Parker, Whitney M. Borland (Courtesy Colorado State University)

3. Sedimentation Activities From 1946 To 1972

After his military service with the 10th Mountain Division as Lt. Col. during WWII from 1942 to 1946 he rejoined the Bureau of Reclamation in 1946 in the Project Planning Division in the newly created Sedimentation Section. His first assignment was under Tom Maddock but with Tom's transfer in 1950 Whit took over the responsibility for guiding the sedimentation program of the USBR. The major categories of work he supervised in the Sedimentation Section of the Bureau of Reclamation were (1) Reservoir Surveys, (2) Distributions of Sediment in Large Reservoirs, (3) Sediment Yields for Drainage Basins, (4) Sediment Transport for Stream Channels, (5) Cooperative Sediment Data Collection with U. S. Geological Survey, (6) Inter Agency Technical Committee on Sediment Sampling Equipment, (7) Design of Stable Channels, (8) Stabilization of Stream Channels, (9) Delta Profiles above and Degradation below Dams, (10) Design of Diversion Dams for Sediment Exclusion, (11) Settling Basin Designs for Canals, (12) Water Surface Profile Computations for Stream Channels and (13) River Bed Scour.

In those activities involving establishment of standards and procedures for use by the Bureau of Reclamation, Whit supervised the preparation of

innumerable reports. Many of these reports served as a basis for a technical paper for presentation at a professional conference of the American Society of Civil Engineers, American Geophysical Union or Federal Interagency Sedimentation Conference. Whit Borland was actively involved with, and maintained personal contacts with, colleagues working on sediment related problems from universities, foreign countries and other governmental agencies. This was accomplished by his participation at professional conferences or symposiums and by serving on Interagency Committees. He maintained an excellent library whereby he and other engineers in the Sedimentation Section could take advantage of new developments and procedures. Whit either authored or co-authored many of the USBR reports and professional papers. Those working for Whit recall his “imaginative” spelling of many words but he would have cherished the present day computer spelling check. One of the authors was advised by Joe Lara when he came aboard, “Always keep in mind, Whit Borland likes answers.”

4. Reservoir Surveys

The field crews from the Sedimentation Section and under Whit’s direction began in 1947 a systematic scheduling of surveys of USBR reservoirs. Criteria for data collection and reporting the results of the survey data was as follows:

1. The survey of large reservoirs was made by establishing a series of range lines
across the reservoir and from the new survey results at these range lines define changes in the area and capacity relationships.
2. The collection of data on sediment deposits consisted of core samples that were analyzed for size gradation and density data.
3. As new and advance designs of either boats, sonic equipment or under water sediment sampling devices became available all efforts were made to update survey procedures
4. The surveys of reservoirs under Whit started with Elephant Butte Reservoir in 1947, Tongue River in 1948, Belle Fourche Reservoir in 1949, and Pathfinder and Seminoe Reservoirs in 1950. The resurveys of USBR reservoirs started by Whit are continuing to date.
5. The reservoir surveys also provided data on the upstream (or delta areas) of the reservoir above the dam and the downstream or degradation of the river channels below the dam.

A portion of the material on reservoir surveys presented in the ASCE, “Sedimentation Engineering,” Manual No. 54, V. A. Vanoni, editor, 1975 contained in Chapter III. —Sediment Measurement Techniques, was prepared by Joe M.Lara under Whit Borland’s direction and review.

5. Distribution Of Sediment In Large Reservoirs

Whit Borland emphasized the need for reports summarizing the reservoir survey procedures and office computations on the results. Besides documenting the data obtained by the surveys the procedures used in the survey are invaluable in conducting future surveys. An objective established by Whit was to gain knowledge from the reservoir surveys for use in predicting the sediment distribution patterns in future reservoirs. Observations of sediment accumulation on many reservoirs in the United States and in many foreign countries where older reservoirs were completely filled with sediment had disproved an earlier concept that sediment deposits were limited to the lower elevations of a reservoir. Under Whit's direction and with Carl Miller's efforts a procedure was developed for predicting the location of sediment accumulation throughout the depth of a reservoir. This procedure is described in the technical report, "Distribution of Sediment in Large Reservoirs" by Borland and Miller and first presented at the Annual Convention, American Society of Civil Engineers in New York on October 17, 1957. In this publication the survey results from 30 reservoirs in the United States data were plotted as percent depth versus percent sediment deposited. He emphasized the important factors influencing the mode of deposition such as: 1. Reservoir shape, 2. Sediment characteristics, 3. Reservoir operation, 4. Sediment-reservoir volume ratio and 5. Inflow-capacity relationship.

Type I through Type IV distribution curves were the four design curves first described in the 1957 publication along with a description of the technique for application of these design curves and formulas to use for predicting sediment deposition patterns in proposed reservoirs. The Bureau of Reclamation policy for large reservoirs is to provide for 100 years of sediment accumulation without encroaching upon the active capacity required for project purposes during that period. The distribution curves he helped developed for forecasting the 100-year sediment accumulation volume influences the design of the dam because of the effect on active storage capacity requirements, outlet sill elevations, recreational facilities, and delta and backwater conditions. Reservoir sedimentation studies by the Bureau of Reclamation are presented in Volume II, Chapter 29, "Reservoir Sedimentation" by W. M. Borland on Reservoir Sedimentation, "River Mechanics," H. W. Shen, ed. 1971.

One example of the international significance of Whit Borland's work is the Bureau's referenced material on reservoir sedimentation contained in the report, "Life of Reservoir" authored by B. N. Murthy. The Technical Report No. 19 by Mr. Murthy was first published in New Delhi, India in March 1977 and reprinted in September 1980. The portion of the report on sediment distribution procedures and methods for estimating the life of a reservoir are similar to the Borland documents.

A unique study on sediment deposition patterns and removal of sediment accumulation by sluicing was undertaken on Guernsey Reservoir on the

North Platte River in Wyoming during the drawdown periods 1960, 1961 and 1962. The reservoir was drawdown from 10 to 15 days twice a year to provide sediment-laden water to the Ft. Laramie Canal and reduce the seepage occurring along that canal. The Sedimentation Section under Whit Borland undertook field investigations during the drawdown periods. Suspended sediment samples were taken for the three-year period. In 1960 and 1962 additional field data included underwater soundings for profiles and channel cross sections, samples of sediment deposits for size gradation, and gamma probe for unit weight of in-situ sediments. Even with the loss of power generation during the drawdown period this method was found to be more economical than mechanical alternatives such as dredging. Several reports were prepared describing the results of the drawdown such as the report, "Sediment Withdrawal—Guernsey Reservoir" by Joe M. Lara dated January 1963.

6. Sediment Yields For Drainage Basins

One technique adopted in the Sedimentation Section was in the plotting of data on the average annual sediment yield versus the drainage area size for prediction of the 100-year sediment volume to be deposited in a proposed reservoir. Data from reservoir surveys from the Interagency Publication on Reservoir Surveys published by various Federal agencies were used in updating the sediment yield relationship.

Other methods selected from the reports in Whit's library were the Universal Soil-loss Equation described by Wischmeier and Smith in 1965 and a favorite often checked by Whit was an analyses of the sediment yield rate factors identified in the report by the Pacific Southwest Interagency Committee, "Factors Affecting Sediment Yield and Measures for the Reduction of Erosion and Sediment Yield," of October, 1968.

Whit Borland conducted sediment yield investigations for a glacial area in Alaska. Two reports were prepared one, "Sediment Study for Vee Project, Susitna River, Alaska," (April 1963) and a second to be found in the Journal of Geophysical Research, "Sediment Transport of Glacier-Fed Streams in Alaska," (October 1961) both authored by Whitney M. Borland.

7. Sediment Transport For Stream Channels

Much of Whit Borland's effort in the late 1940's and the 1950's was in the collection and analysis of sediment sampling data for determining the total sediment transport of river channels. This was a period where the suspended sediment sampling equipment was being used to measure the suspended sediment load of a stream at a given water discharge. However, the bedload or truly the "unmeasured" portion of the total sediment load was being computed by one of the several bedload formulas. Whit recognized the importance of better defining the total sediment load of a river channel in a more accurate prediction of sediment inflow to a proposed reservoir, sediment inflow to a diversion dam, sediment loads at riverbank pumping plants, design of stable channels, and erosion of riverbanks requiring

stabilization measures. The importance of research in total sediment load was a special concern for those stream channels with a sand size bed material such as the main channel and tributaries of the Platte River, Canadian River, Rio Grande, and the Colorado River. These rivers exemplified channels of sand size material where the bed load as computed by use any of the better known bedload formulas could vary from as much as 5 to 150 percent of the total load.

It was through the efforts of Maury Albertson at Colorado State University, Paul Benedict with the U. S. Geological Survey in Lincoln, Nebraska and Whit Borland from the Bureau of Reclamation that the Dunning Flume on the Middle Loup River in Nebraska was first model tested and then constructed under the highway bridge at Dunning, Nebraska. The model testing was described in the report, "Design of the Loup Bed-Load Measurement Structure," as prepared for the U.S. Geological Survey by the Civil Engineering Section of Colorado State University at Fort Collins, Colorado, July 1948. The U. S. Geological Survey and the Bureau of Reclamation, both of the Department of Interior, completed the structure early in the summer of 1949. The flume construction located under the bridge consisted of an alternating series of baffles that extended from the floor under the bridge up and into the water prism with the downstream portion of the flume being a wooden stop log or turbulence-sill where measurements could be taken by use of the hand held DH-48 suspended sediment sampler. Sediment sampling at the Dunning turbulence-sill on the Middle Loup River began on August 17, 1949. In addition to suspended sediment measurements at the turbulence-sill a normal stream channel suspended sediment measuring section both upstream and downstream of the bridge was established for comparison purposes.

A second total sediment load sampling station as recommended by Whit Borland was on the Niobrara River near Cody, Nebraska where sampling started in March 1950. A natural restriction in width of the Niobrara River (actually a "hole-in-the rock") provided a location where the turbulence combined with extreme high velocities permitted conditions where the total sediment load could be measured by a depth integrated suspended sediment sampler. Downstream from this narrow gorge type channel the Niobrara River formed a more natural channel with sand size bed material.

In the 1950's the most reliable of the many bedload formulas (as selected by Whit) were the Einstein, Schoklitsch, Meyer-Peter Muller, Kalinske, and the Lane-Kalinske formulas. During the sampling period in 1949 and 1950 Whit Borland contacted Dr. Hans Albert Einstein at the University of California in Berkley, California to determine his interest in the project. Dr. Einstein visited the Dunning total load sampling site and as a result in April, 1950 entered into a contract for limited participation during May of 1950 with the Bureau of Reclamation for application of his new total load formula to the data being collected at the Dunning turbulence-sill. Einstein published his report, "The Bed-load Function for Sediment Transportation in Open

Channel Flows,” Technical Bulletin No 1026 of the U. S. Department of Agriculture, Soil Conservation Service in September 1950.

A special study conducted by the Sedimentation Section in 1960 was to analyze the sediment transport of Bridge Creek, a tributary to the Colorado River underneath the arch at Rainbow Bridge National Monument on Lake Powell above Glen Canyon Dam. A combination of prediction of the sediment load and delta formation on Bridge Creek with the addition of a tunnel diverting the sediment load into the adjacent Aztec Creek are described in the Bureau report, “Sedimentation Studies, Rainbow Bridge Protective Works,” of June 1960 by Whit Borland and Ernie Pemberton.

In the 1960’s, a successful effort was made by the Sedimentation Section in the development of a computer program for the Einstein Bed-Load Function from the 1950, - Bulletin 1026 and the Modified Einstein Procedures as “more modified” by the Bureau of Reclamation by Gene Cristofano.

8. Cooperative Sediment Data Collection With U.S.Geological Survey

In the 1950’s the Sedimentation Section of the Bureau of Reclamation in addition to the above described research activities, continued work on setting up a standard method for predicting the 100-year sediment inflow to reservoirs. This was accomplished by funding the U.S. Geological Survey in the establishment of a suspended sediment sampling in conjunction with a stream discharge measuring station. In many cases the Bureau considered approximately 5 years of sampling were required for computing an average annual sediment load. The procedure adopted by the Bureau under Whit Borland for computing the average annual sediment load at a sampling station as operated by the U. S. Geological Survey was described in the report, “Analysis of Flow-Duration, Sediment-Rating Curve Method of Computing Sediment Yield,” by Carl Miller in April, 1951. The sediment-rating curve was derived from a logarithmic plot of water discharge in cubic feet per second versus suspended sediment load in tons per day.

The example of a cooperative program between two Governmental agencies, the Bureau of Reclamation and the U.S. Geological Survey, was in the construction and sampling at the Dunning turbulence-sill on the Middle Loup River in Nebraska. Water discharge measurements and suspended sediment samples were collected with personnel working side by side from the two agencies. The success of this program was directly attributed to the progressive action of Paul Benedict of the Geological Survey in Lincoln, Nebraska and Whit Borland of the Bureau of Reclamation. It was through these cooperative efforts that the sampling on the Niobrara River near Cody, Nebraska was undertaken. Research on total sediment load was being conducted jointly within the Bureau of Reclamation and the U.S.Geological Survey with Einstein’s Bed-Load Function serving as a basis for much of this research. The Sedimentation Section worked on the development of a Modified Einstein Procedure which made adjustments to the Einstein Bed-

Load Function. The U.S. Geological Survey report, "Computation of Total Sediment Discharge, Niobrara River near Cody, Nebraska," of 1955 by Colby and Hembree described the Modified Einstein Formula. Although the final report on development of the Modified Einstein Method was written by Colby and Hembree of the Geological Survey considerable work was proceeding on its development in the Sedimentation Section in Denver, Colorado with Whit Borland and his assistant, Ken Schroeder.

The benefits of two agencies cooperating in construction and collection of sediment data was carried over to the sampling program by the U. S. Geological Survey and the Bureau of Reclamation on the Rio Grande from Bernalillo downstream to near Socorro, New Mexico in the 1950's.

9. Inter Agency Technical Committee On Sediment Sampling Equipment

Whit Borland served on the Technical Committee of the Interagency Sedimentation Subcommittee overseeing the activities on development of sediment sampling equipment from 1946 until 1970 at the St. Anthony Falls Hydraulic Laboratory in St. Paul, Minnesota. It was on this committee that he shared his ideas and gained many new ideas from other committee members. Through this period the major forces on the committee were known as the "Three B's". That group of Paul Benedict, from the U.S. Geological Survey, Don Bondurant, from the Corps of Engineers and Whit Borland, from the Bureau of Reclamation helped guide the work forces at the laboratory first under the direction of Byron Colby and after 1965 directed by John V. Skinner.

10. Design Of Stable Channels

Earlier reports (prior to 1950) on stable channels by E. W. Lane and the report prepared Lane in June 1952 on "Progress Report on Results of Studies on Design of Stable Channels," Bureau of Reclamation Hydraulic Laboratory Report No. Hyd-352 provided support for criteria adopted by Whit Borland. The Hyd-352 report by E. W. Lane favored the use of tractive force for use in design, but supported further studies.

In a report that Whit Borland co-authored with Pete Terrell of the Bureau's Canal Branch in the Design Division, entitled "Design of Stable Canals and Channels in Erodible Material," (undated but sometime between 1953 and 1955); the authors indicated that for channels in erodible material a stable design is a complex problem. They stated that the approach for analyzing channel stability is one requiring the application of knowledge of the channel hydraulics and the sediment transport. For a stable channel design by the Bureau of Reclamation a combination of approaches was recommended. The combination included a theory proposed by Luna B. Leopold and Thomas Maddock, Jr. in their U.S. Geological Survey Professional Paper 252, entitled, "The Hydraulic Geometry of Stream Channels and Some Physiographic Implications," dated 1953. Another approach recommended is to use that described by Thomas Blench and later

published in his book, "Mobile-Bed Fluviology," dated 1969. A direct quote from the paper by Terrell and Borland regarding the combination approach is as follows:

"For example, the Maddock-Leopold and Blench procedures will give a width at the dominant discharge. This width is then checked to see if the sediment will be transported. If this checks, then the bank tractive forces are checked. If the bank tractive forces are too high for the bank material to resist, then additional barriers such as riprap, vegetation, and revetments are needed. If the bank and bed material show considerable more allowable tractive force, then the channel will remain stable at a narrower width as dictated by the bank and bed allowable tractive force. Transport will almost always be greater than required with the narrower widths."

Besides being a complex problem, Terrell and Borland indicated that design of stable channels is the type of engineering that does not lend itself to precise design and is dependent upon the judgment, experience and skill of the engineer.

In a paper, "Stream Channel Stability," by Whit Borland, undated but estimated between 1953 and 1955, he indicated that to understand the natural phenomena an engineer resorts to cycles and balances. He stated that in channel stability the hydrologic cycle, the physiographical balance and the fluvial balance somewhat simplify natural processes. Whit in this report stated that the fluvial balance might be expressed by proportionality:

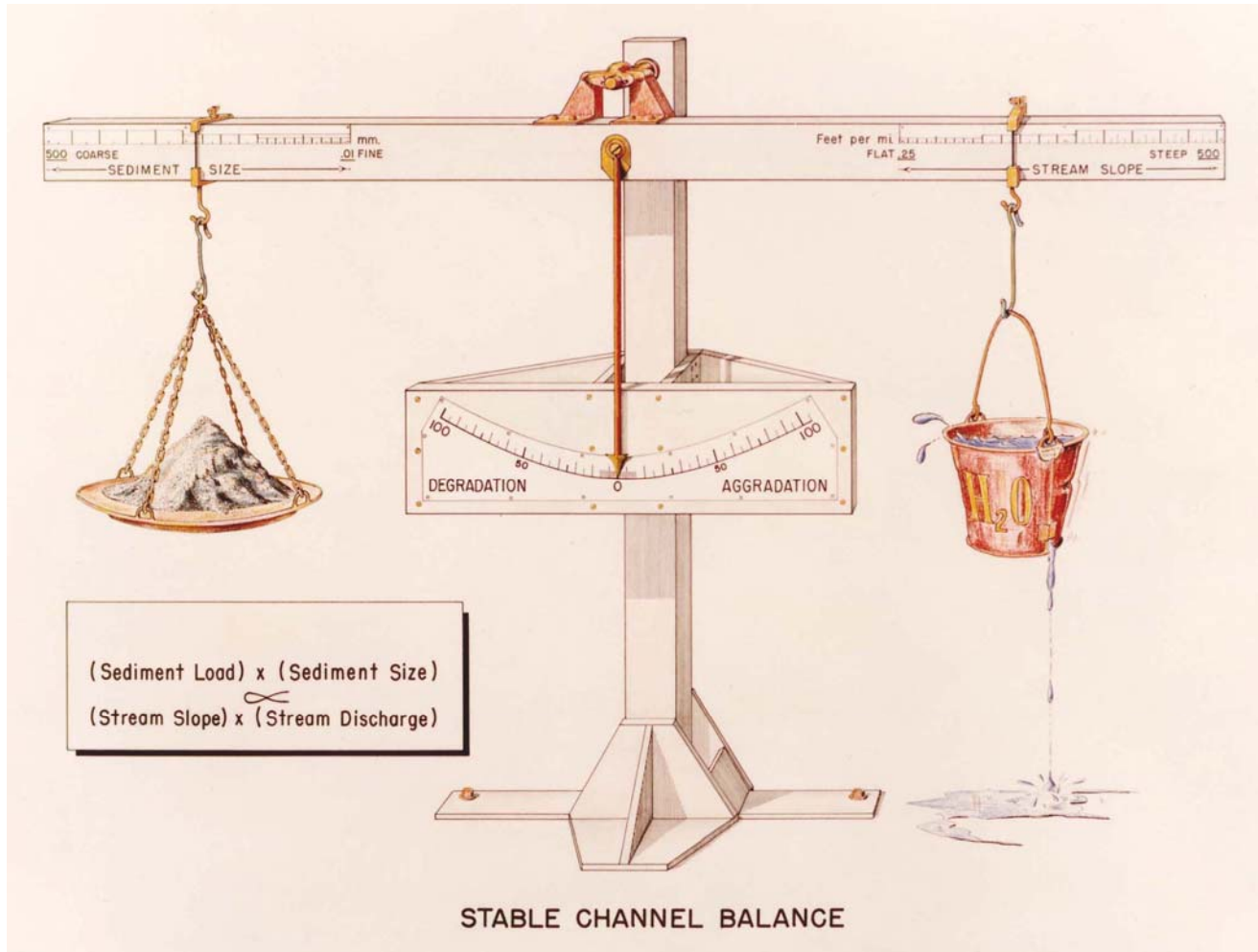
(Sediment load) x (sediment size) is proportional to (stream discharge) x (stream slope)

The above proportionality was designed by Whit using the same terms in a balance scale and is shown below.

The only reference Whit made to E. W. Lane was the graphs Lane had presented relating the limiting tractive force to particle size. E. W. Lane in his 1955 report, "The Importance of Fluvial Morphology in Hydraulic Engineering," published in the Proceedings, of ASCE stated that:

$$QS \propto Q_s D_{50}$$

which is similar to that by Whit Borland and the two identical proportionalities reported about the same time may have resulted from their personal communications.



(Illustration Courtesy of James Vitaliano, Bureau of Reclamation)

11. Stabilization Of Stream Channels

River channel stabilization projects of the Bureau of Reclamation conducted under the guidance of Whit Borland include these: (1) Stabilization of Fivemile and Muddy Creeks in Wyoming, (2) Stabilization of the Middle Rio Grande in New Mexico, (3) Bank and Levee Stabilization on Lower Colorado River on border of Arizona and California, (4) Channel Stabilization of Azotea and Willow Creeks in New Mexico, and (5) Stabilization of Frenchman Creek in Nebraska. In the above examples the variation in type of problems, technical analysis supporting design techniques, and construction methods selected for establishing stability are described below.

Stabilization of Fivemile and Muddy Creeks in Wyoming. Changes in regime had occurred with increase in flows due to waste flows and irrigation return flows. As a result of these changes computations by a regression equation depicting sediment loads by Leopold-Maddock Equation was

combined with tractive forces and channel hydraulics by Manning's Equation for defining stable channel widths. Construction on Fivemile Creek was the planting of willow and Russian olive seedlings within a width controlled by use of jack fields. Baffle apron drop structures were added when natural rock controls failed. Muddy Creek was stabilized by maintaining the original channel lengths and meander patterns with the planting of various types of willows and seeding sweet clover.

In addition to Bureau of Reclamation reports on the project, the stabilization measures are described in the paper, "Stabilization of Fivemile and Muddy Creeks," by C. R. Miller and W. M. Borland, ASCE, Journal of Hydraulics Division of January 1963.

Stabilization of the Middle Rio Grande in New Mexico. Channel stabilization in an approximate 115-mile reach was accomplished by developing a more efficient channel for transport of sediment in order to reduce the rate of aggradation in the Rio Grande floodway from Cochiti Diversion Dam to San Acacia Diversion Dam. Sediment sampling data collected at the regular stream gauging stations by the U.S. Geological Survey and the additional special measuring reaches established under the cooperative program of the Bureau of Reclamation and the U. S. Geological Survey were used in a regression analysis. The analysis resulted in width of open channel for transporting the sediment inflow as controlled by fields of steel jacks. The construction of the jack fields was a cooperative endeavor between and Bureau of Reclamation and the Corps of Engineers in Albuquerque, New Mexico. After construction Whit participated in the annual examination of the effectiveness of the jack installation and made recommendations on any remedial measures necessary.

Bank and Levee Stabilization, Lower Colorado River on the Border of Arizona and California. Dams on the Colorado River i.e., Hoover Dam, Davis Dam, Parker Dam and the downstream Imperial Diversion Dam had resulted in many river channel problems caused by the regulation of water discharges together with the changes in sediment loads. In the approximate 280 miles from Davis Dam to the Southerly International Boundary with Mexico, physical conditions vary from a river channel supplying downstream water uses, to reaches of reservoir, and to a low flow channel conveying, essentially, drainage water. In the early 1940's and after closure of Hoover Dam in 1935 a sediment deposition or aggradation of the river threatened the town of Needles and the Santa Fe Railroad upstream from Parker Dam. To alleviate the aggradation at Needles a dredge was placed into operation on the Colorado River in February of 1949. The ASCE Journal of Hydraulics Division report, "Sediment Problems of the Lower Colorado River," by Whitney M. Borland and Carl R. Miller dated April, 1960 describes the sediment studies conducted for defining the optimum width of the channel by use of the Maddock-Leopold regression equation with tractive force, the Schoklitsch bedload and the Lane method described in his 1955 report on "Design of Stable Channels."

The stabilization techniques used on the Colorado River have varied for improving, modifying, straightening, and rectifying the river by use of dredging, levee protection, and riverbank stabilization. In most areas above Imperial Diversion the design width for dredging was 450 feet with the stable stream slope of 1.2 feet per mile or 0.00023 ft./ft. In the dredged areas the minimum radius of curvature for all bends was about 5,000 feet. Whit continued on the project after various phases were constructed and made regular inspections to assure adequate maintenance.

Channel Stabilization of Azotea and Willow Creeks in New Mexico.

Under the San Juan–Chama Project of the Bureau of Reclamation flows are diverted from the San Juan Mountain area in Colorado into the Rio Chama basin. in New Mexico. Additional water is diverted through the Azotea Tunnel directly into the Azotea Creek and then into Willow Creek before reaching Heron Reservoir on the Rio Chama. The procedures for analyzing stability and potential erosion were by use of the tractive force and streambed bottom velocities for stability. The slope of the existing channels for the five reaches investigated varied from approximately 0.3 to 0.6 percent. With the large increase in dominant discharge the method selected for controlling bank and bed erosion was to place riprap along both banks and utilize baffle apron drop structures.

Stabilization of Frenchman Creek in Nebraska. Frenchman Creek below Enders Dam in Nebraska was undergoing bank erosion and loss of farmland due to the longer duration of sustained releases to the channel for diversion into the downstream Culbertson Canal. The ultimate channel widths for Frenchman Creek were analyzed by use of the Maddock-Leopold regression equation and the tractive force procedures. Methods tested to control the bank erosion were wooden fences and bank line rows of wire fence between wood piling and jacks. Because of the meandering characteristic of the channel and narrow widths the steel jacks were selected and were well anchored and cabled along the outside bends. In areas where oxbows had been cut off by bank erosion at the narrow point, jacks were used to restore the channel to its original length.

Field observations and data were collected during November 1967 on Turkey Creek in Nebraska by the Sedimentation Section on the channel hydraulic characteristics prior to possible channel stabilization measures. The procedures of data collection and the channel stability studies are described in the report, “Turkey Creek Channel Stability Studies, Farwell Unit, Middle Loup Division, Pick-Sloan Missouri Basin Program,” dated January 1971 by R.I. Strand.

12. Delta Profiles Above And Degradation Below Dams

Reservoir surveys provided data on sediment deposition patterns at the upstream or delta portion of the reservoir. In the reservoir reports by the Bureau of Reclamation, Whit Borland also included a definition of the

distribution of sediment longitudinally to include the delta profile. The consequences of the delta deposits of sediments raising the backwater elevations in the upstream channel has an influence of upstream structures such as bridges, urban developments and recreational facilities. The prediction on the delta development is a complex problem because of the variables such as operation of the reservoir, sizes of sediment, and main channel hydraulics. In analyzing the sediment deposition patterns from reservoir surveys, the studies conducted by Whit identified delta formation and illustrated the typical longitudinal profiles of sediment deposits as defined by a topset slope, foreset slope, and bottomset slope. He established the definition of the break point between the topset slope and foreset slope as a pivot point. This pivot point was identified as approximating a 50 percent reservoir operating elevation.

Special delta studies were undertaken in the Sedimentation Section on the location and magnitude of the topset and foreset slopes for use in prediction of delta formation. The techniques found to best describe the topset slope was a combination of two possible methods. One method was a regression analysis of topset slopes from surveys as related to the original stream channel slope. The other method was the computation of one or more bedload equations to a zero transport at the dominant discharge. Another result of studies conducted by Whit was the average of foreset slopes observed in Bureau of Reclamation reservoir surveys of 6.5 times the topset slope.

Preliminary studies by Whit Borland in April 1963 were made on the delta formation for design of a pumping plant on the Bill Williams arm of Havasu Lake for the Central Arizona Project in Arizona. After sediment surveys of 1963, 1964, and 1970 on Bill Williams River arm of Havasu Lake a detailed study on delta development and projection to 150 years, a report, "Final Design Sediment Deposition Study," dated September 1970 was prepared by Ernest L. Pemberton for use in design of dikes and inlets to the Central Arizona Pumping Plant at Havasu Lake on the Colorado River above Parker Dam.

Either reservoir surveys or special surveys were made by the Bureau of Reclamation under Whit Borland's direction for defining the degradation downstream from a dam. With the trapping of sediment in a reservoir accompanied by clear water releases the downstream channels were no longer stable and were subject to channel bank and bed erosion. One of the first Bureau of Reclamation reports was an unpublished study, "Tail Water and Degradation Studies, Colorado River below Glen Canyon," dated 1957, by C. R. Miller and W. M. Borland. A follow up report made during the construction of Glen Canyon Dam was the degradation studies described in Whit's report, "Degradation of Colorado River channel downstream from Glen Canyon Dam Site—Colorado River Storage Project," dated October 31, 1960. During the construction of Glen Canyon in July 1959 changes in tailwater below the dam were of concern to the operation of the powerplant at

the dam. Investigations of tailwater changes and channel stability were undertaken and described in a Sedimentation Section report, "Channel Changes in the Colorado River below Glen Canyon Dam," in 1975 by Ernest L. Pemberton.

In September 1953, a study was undertaken by the Sedimentation Section to determine the extent of degradation that could be expected downstream from the Milburn Diversion Dam on the Middle Loup River in Nebraska. This was followed by surveys of established channel cross sections in 1961, 1964 and 1967. The results are described in the report, "Behavior of Middle Loup River Channel as Influenced by Milburn Diversion Dam," of May 1968 by Robert I. Strand

In the Design of Small Dams by the Bureau of Reclamation as printed in 1973, 1977 and 1987 one Appendix is on Sedimentation, which describes the above-described material on Reservoir Sedimentation and includes material on "Downstream Channel Effects," prepared by Robert I. Strand and Ernest L. Pemberton.

13. Design Of Diversion Dams For Sediment Exclusion

One aspect of Whit Borland's experience in the Sedimentation Section was his continued interest in the design of the Bureau's construction projects. One of the most intriguing problems in design was in the design of a diversion dam for reducing the inflow of sediment into an irrigation canal. This interest began with his first job with the Bureau of Reclamation from 1930 until 1936. In that period he was in charge of the hydraulic laboratory at Montrose, Colorado, which included the testing and preparing of a report on Imperial Diversion Dam on the Colorado River for diversion into the All American Canal. Prior to the 1950's most diversions by private engineering companies as well as the Bureau of Reclamation relied on some type of sluice gate and sluiceway with the sill of the sluiceway set at a lower elevation than the headgate elevation of the canal intake. In many of these there remained sufficient turbulence at the point of diversion that resulted in the diversion of the heavier concentrations of suspended sediment near the bed and large quantities of the coarse bed material size sediments.

Model tests starting in the 1950's by the Hydraulics Laboratory of the Bureau of Reclamation were conducted for design of diversion structures for excluding the coarser sand and gravel size sediments from irrigation canals. The design features tested and constructed by the Bureau of Reclamation of a diversion structure for excluding the coarser bed material fraction of the total load consisted of the following:

1. Divert water on the concave bend by construction of a curved training wall
2. Rely on natural stream channel curvature
3. Undersluice tunnel with diverted water over top of tunnel
4. A grated drop inlet at bottom of channel

5. A modification to the vortex tube at the headworks intake for bypassing the coarser bed load material.

In the 1960's the Sedimentation Section, under Whit Borland's guidance, started a sediment sampling program to test the effectiveness of the diversion structures modifications such as the curved guide wall at the Superior-Courtland Diversion Dam on the Republican River in Nebraska and the under sluice tunnels at the Milburn and Arcadia Diversion Dams on the Middle Loup River in Nebraska.

14. Settling Basin Designs For Canals

Prior to the 1950's diversion dams designed with sluiceways like those on the Rio Grande at Angostura and Isleta diversion dams in New Mexico, settling basins were provided at the upper end of an irrigation canal. The settling basins were enlarged sections in the upper reaches of the canal where the velocities could be reduced to from 0.5 to 1.0 feet per second. The sand or coarser material (>0.0625 millimeters) would be trapped in the settling basin and removed by dredging or sluicing back to the river. A similar type settling basin was constructed at Imperial Dam on the Colorado River for the Gila Main Canal at the diversion dam. The design criteria for settling basins by the Bureau of Reclamation prior to the late 1960's was described in the report, "Technical Aspects of the Silt Problem on the Colorado River," Civil Engineering, ASCE November 1940 by C.P. Vetter.

In the late 1960's the Sedimentation Section under the direction of Whit Borland prepared a report, "A Procedure to Determine Sediment Deposition in a Settling Basin," dated August 1971 by Ernest L. Pemberton and Joe M. Lara. This report summarized the technique by Vetter with the method described in the report, "Final Report Spawning Grounds," University of California in 1965 by H. A. Einstein. The two procedures developed by Vetter and Einstein were found to be almost identical. One test of the settling basin design equations was conducted on the Socorro Main Canal at the San Acacia Diversion Dam on the Rio Grande near Socorro, New Mexico. The volume of material deposited and dredged from the settling basin was determined for the period from March 1 to June 21, 1956. The sediment deposited in the basin during that period was 53,250 tons, or about 13% less than the settling basin design equations indicated.

15. Water Surface Profile Computations For Stream Channels

Whit Borland's background in the backwater subcritical flow computations which he conducted on the Columbia River above Grand Coulee Dam in the early 1940's served as a basis for continuing that work in the Sedimentation Section. There was also a need for water surface profiles to define the channel hydraulics in the application of bedload or total load sediment transport equations. In addition to their use in sediment transport computations, water surface profiles are required for design purposes for defining the tailwater at a dam, diversion dam or riverbank power or pumping plants. Another use is to derive backwater curves upstream from the reservoir

for land acquisitions, easements and any upstream structures. A detailed description of the procedures are given in the report, "Guide for Computing Water Surface Profiles," dated November 1957 by Joe M. Lara. A summary of the procedure is given in the paper, "Two Methods to Compute Water Surface Profiles," of April 1959 in the ASCE Journal of the Hydraulics Division by Joe M. Lara and Kenneth B. Schroeder.

The Sedimentation Section developed a computer program as given in the paper, "Guide for Application of Water Surface Profile Computer Program," dated December 1968 by Gene Cristofano. This program known as the "PSEUDO" program was used by the Bureau of Reclamation for many years and when checked gave similar results as the Corps of Engineers program, "HEC-2."

16. River Bed Scour

Scour of a riverbed during a major flood event was an important design feature for the Bureau of Reclamation at channel bankline structures and in the use of siphons for a canal crossing. A joint effort by E. W. Lane and W. M. Borland on maximum scour of riverbeds was undertaken and described in an ASCE Proceedings paper No. 2712, "River-Bed Scour During Floods," (August 1953). The paper described the variations in scour occurring at bends, crossings between bends and at narrow sections from observations at gauging stations on the Colorado River, the Rio Grande and the Yellow River in China. A study on scour at siphon crossings was conducted under Whit's direction and reported in a memorandum dated May 12, 1959 by E. A. Jarecki. Another study authored by Whitney M. Borland was one dated February 3, 1965, on estimating the scour at a main canal siphon crossing of Gobernador and Largo Canyons in New Mexico.

17. Summary

During the period from 1950 until 1972, Whit Borland was responsible for guiding the sediment program for the Bureau of Reclamation. He was a man of vision and as a professional engineer was responsible for development of new procedures in his specialty, sedimentation. He undertook new challenges and was always striving for updating the sedimentation investigations and responsibilities in the Bureau of Reclamation. He encouraged and actively took part in the preparation of professional papers as an author or co-author at professional meetings conducted by American Society of Civil Engineers, the Federal Interagency Sedimentation Committees, the American Geophysical Union, Colorado State University, and others.