Whitney M. Borland and the Bureau of Reclamation, 1930–1972

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Introduction

Whitney McNair Borland was born November 6, 1905, in Holyoke, Colorado, and died in Peoria, Arizona, on October 2, 2001. He began his career with the United States Bureau of Reclamation (USBR) in 1930, and in 1972 he retired from the bureau after distinguishing himself throughout the world in the sedimentation field. Within the bureau USBR he was known as “Mr. Sediment” in research, planning, construction, and operation and maintenance of irrigation, hydroelectric, and municipal water projects.

Whit’s education began with a bachelor’s degree from the University of Nebraska and a master’s degree from the University of California at Berkeley, both in mechanical engineering. While working for the USBR, he obtained a master’s degree in civil engineering from the University of Colorado in 1938. Whit’s career in the USBR spanned two periods, one from 1930 until 1942, and a second after World War II from 1946 to 1972. Whit served with the 10th Mountain Division during World War II (from 1942 to 1946) where he rose to the rank of lieutenant colonel.

The Early Years

Borland’s first assignment with the USBR in 1930 was in the hydraulic laboratory at Montrose, Colorado, testing models for the Imperial, Grand Coulee, and Stewart Mountain Dams. He then worked on the addition to the hydraulics laboratory at Colorado State University, which was followed by part-time work at the laboratory in the design, construction, and testing of models for other USBR 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, which included channel improvements for decreasing backwater impacts. From this study he prepared a report for the International Boundary and Water Commission. Because of his background in computing water-surface profiles he established a reputation as the bureau’s top engineer in river channel hydraulic computations.

After the War

He rejoined the USBR in 1946 in the newly created sedimentation section of the Project Planning Division. His first assignment was under Tom Maddock, and in 1950 Whit took over the responsibility for guiding the sedimentation program of the USBR, which he continued until 1970. In those activities involving establish-

ment of standards and procedures for use by the USBR, Whit supervised the preparation of innumerable reports. Bob Strand, who later joined the Sedimentation Section, was advised by Joe Lara, “Always keep in mind, Whit Borland likes answers.” Whit encouraged the use of these USBR reports as a basis for a technical paper for presentation at a professional conference of the American Society of Civil Engineers, American Geophysical Union, and the Federal Interagency Sedimentation Conference.

Many activities outside of the USBR interested Whit. His enthusiasm for diagnosis of engineering problems was well supported by his natural mechanical ability, which included automobile engine rebuilding. An avid and active member of the Colorado Mountain Club, he enjoyed 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 to his fellow 10th Mountain Division veterans, he was also involved with the avalanche studies for the ski resort at Vail, Colorado.

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 in Thailand and Laos. After retirement in 1972 Whit became a consultant on numerous projects. With his

Fig. 1. Whit Borland before retiring from Bureau of Reclamation in 1972 (courtesy of Borland Family)

Fig. 2. 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)

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.

Whit coauthored many technical engineering professional papers with colleagues at the bureau. However, he maintained a special and mutual interest in sedimentation research with Emory W. Lane. This forum article highlights many of the reports he authored or coauthored with bureau colleagues and Sedimentation Section employees.

Reservoir Surveys

Sedimentation section field crews, under Whit's direction in 1947, began a systematic scheduling of surveys of USBR reservoirs. The surveys of reservoirs started with Elephant Butte Reservoir in 1947, Tongue River in 1948, Belle Fourche Reservoir in 1949, and Pathfinder and Seminole Reservoirs in 1950. A major undertaking on reservoir surveys and collection of data on densities and underwater sediment characteristics was the 1963–1964 survey of Lake Mead described by Lara and Sanders (1970). The sediment density gamma probe used on Lake Mead was shown in the report by Murphy (1964).

The resurveys of USBR reservoirs started by Borland are continuing to date. A report on USBR reservoir surveys as prepared by Joe M. Lara under Borland's direction and review was published in the ASCE sediment manual, edited by Vanoni (1975).

Distribution of Sediment in Large Reservoirs

Borland emphasized the need for reports summarizing the reservoir survey procedures and office computations of the results. Besides documenting the data the procedures used in the survey are invaluable in conducting future surveys. An objective established by Borland was to gain knowledge from the reservoir surveys for use in predicting the sediment distribution in future reservoirs. Under Borland's direction and with Carl Miller's efforts,

a procedure was developed for predicting the location of deposition throughout the depth of a reservoir. This procedure is described in the technical report by Borland and Miller (1958). 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 including reservoir shape, sediment characteristics, reservoir operation, the sediment–reservoir volume ratio and the inflow–capacity relationship.

Type I through Type IV distribution curves were the four design curves described in the 1960 publication, along with a description of the technique for application of these design curves and formulas to predict sediment deposition in proposed reservoirs. The distribution curves he helped develop for forecasting the 100-year sediment accumulation volume influences dam design due to the effect on active storage capacity, outlet sill elevations, recreational facilities, and delta and backwater conditions. The density usually identified as unit weight or specific weight for use in converting sediment weight to volume was described by Miller (1953) and later modified by Lara and Pemberton (1963). Reservoir sedimentation studies by the USBR are presented by W. M. Borland (volume II, chapter 29) in the publication "River Mechanics," edited by Shen (1971).

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 in 1960, 1961, and 1962. The reservoir was drawn down for 10–15 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 Borland, undertook field investigations during the drawdown periods with suspended-sediment samples collected during 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.

Reports describing the results of the drawdown were prepared by Lara (1963) and Jarecki and Murphy (1963).

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. Whit also conducted sediment yield investigations for a glacial area in Alaska, and two reports were prepared Borland (1961, 1963).

Sediment Transport for Stream Channels

Much of Borland's effort in the late 1940s and the 1950s was in the collection and analysis of sediment sampling data for determining the total sediment transport of river channels. This was a period where equipment was being used to measure the suspended sediment load of a stream at a given water discharge. However, the bedload, or "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 for more accurate predictions of sediment inflow into reservoirs, sediment inflow to diversion dams, sediment loads at riverbank pumping plants, design of stable channels, and riverbank stabilization. The importance of research in determining 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. In a report by Lane and Borland (1951), a table was presented for use in estimating bedload with percent bedload in terms of measured suspended load. Values shown varied from below 5% to as high as 150% of the suspended load depending on suspended-load concentrations and the size gradation of the suspended and bed material.

It was through the efforts of Maury Albertson at Colorado State University, Paul Benedict with the U.S. Geological Survey (USGS) in Lincoln, Nebraska, and Whit Borland that the Dunning turbulence-sill 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 prepared for the USGS by the Civil Engineering Section of Colorado State University (1948). The USGS and the USBR completed the structure early in the summer of 1949. The flume 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. 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 Borland was on the Niobrara River near Cody, Neb., where sampling started in March 1950. A natural width restriction of the Niobrara River (actually a hole in the rock) provided a location where the turbulence combined with extreme high

Fig. 3. Collection of suspended-sediment samples at the Dunning turbulence-sill for total sediment load measurements on the Middle Loup River, Nebraska (courtesy U.S. Geological Survey)

velocities permitted conditions where the total-sediment load could be measured by a depth integrated suspended sediment sampler.

During this time Borland contacted Dr. Hans Albert Einstein at the University of California at Berkeley 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. Ernie Pemberton of the USBR applied the Einstein new total-load formula on data being collected at the Dunning turbulence-sill, which provided an early application of the bed-load function by Einstein (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 by Borland and Pemberton (1960).

Interagency Technical Committee on Sediment Sampling Equipment

Borland served on the technical committee of the Interagency Sedimentation Subcommittee overseeing the 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. Throughout this period the major forces on the committee were known as the "Three B's": Paul Benedict, from the U.S. Geological Survey; Don Bondurant, from the Corps of Engineers; and Whit Borland. This group helped guide the work forces at the laboratory first under the direction of Byron Colby, and after 1965, by John V. Skinner.

Design of Stable Channels

The Sedimentation Section, under Borland, conducted field investigations for testing the criteria first developed by Lane (1952)

Fig. 4. Whit Borland in discussions with Paul Benedict [U.S. Geological Survey (USGS)], Dave Hubbell (USGS), Bob Livesey (Corps of Engineers), and Jim Culbertson (USGS) at 3rd Federal Interagency Sedimentation Conference, Denver, Colorado, in 1976

and being used by the USBR in the design of stable channels. E. W. Lane favored the use of tractive force for use in design, but supported further studies. In a cooperative study with the bureau's Canal Branch in the Design Division, Terrell and Borland (1956) indicated that for channels in erodible material, achieving stability is a complex design problem. A combination of approaches was recommended, including applying theories proposed by Leopold and Maddock (1953) or techniques later described by Blench (1969). Terrell and Borland indicated that design of stable channels does not lend itself to precise design and is dependent upon the judgment, experience, and skill of the engineer.

A stream channel stability paper by Borland (1960a,b) 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. Borland (1960a,b) stated that the fluvial balance might be expressed by the proportionality: "(Sediment load) $\times$ (sediment size) proportional to (stream discharge) $\times$ (stream slope)." Borland conceived this proportionality as a balance scale, and with the help of a USBR artist, developed his "stable channel balance."

Lane (1955) preceded Borland in the presentation of a stability-type relationship for defining equilibrium of a natural stream channel. Lane presented the following as a general expression for use in a qualitative evaluation of the stream morphology by

$$Q_w S \sim Q_s d \quad (1)$$

in which Q_w and Q_s = water and sediment discharges, respectively; S = slope of the stream, and d = particle diameter or size of the sediment.

The personal communications of Whit Borland and Emory Lane in their work at the Denver office of the USBR prior to 1960 and in coauthoring numerous technical papers would explain their use of a similar channel stability relationship in technical reports.

Credit for the qualitative relationships should be given to Lane (1955) and the balance scale should be attributed to Borland (Fig. 5).

Stabilization of Stream Channels

River-channel stabilization projects of the USBR conducted under the guidance of Borland include: stabilization of Fivemile and Muddy Creeks in Wyoming, stabilization of the Middle Rio Grande in New Mexico, Bank and Levee stabilization on Lower Colorado River on the border of Arizona and California, channel stabilization of Azotea and Willow Creeks in New Mexico, and stabilization of Frenchman Creek in Nebraska.

Construction on Fivemile and Muddy Creeks identified by Miller and Borland (1963) included the planting of willow, Russian olive, and sweet clover seedlings, jack fields for controlling channel widths, baffle apron drop structures, and controls to maintain the original channel lengths. Rio Grande stabilization shown by Woodson (1961) included jack fields for maintaining an open channel width for transporting the sediment inflow. In the reach of the Rio Grande immediately above Elephant Butte Reservoir, a low-flow channel and adjacent floodway were constructed to more efficiently transport water into the reservoir. On the Colorado River in the reaches downstream from Hoover Dam to below the Imperial Diversion Dam, Borland and Miller (1960) described several techniques used for modifying, straightening, and rectifying the river by dredging, levee protection and river-bank stabilization to reduce bank erosion, and the sediment deposition and aggradation. With the large increase in dominant discharge on Azotea and Willow Creeks, USBR (1966), due to transbasin imports (the method selected for controlling bank and bed erosion), was to place riprap along both banks and to utilize baffle apron drop structures. On Frenchman Creek below Enders Dam, Frogge (1967) identifies where the steel jacks were

Fig. 5. Initial visit in 1949 to San Luis Valley canals by C. W. Thomas, E. W. Lane (shown in photo) and E. L. Pemberton for stable channel studies by Bureau of Reclamation

anchored and cabled along the outside bends and used to control bank erosion caused by longer duration and sustained flow releases.

Delta Profiles above and Degradation below Dams

In the reservoir reports by the USBR, Borland also included a definition of the distribution of sediment longitudinally to include the delta profile. Delta deposits of sediments raise the backwater

elevations in the upstream channel and influence of upstream structures such as bridges, urban developments, and recreational facilities. The prediction of the delta development is a complex problem because of the variables, including reservoir operation, sediment size, and channel hydraulics. In analyzing the sediment deposition patterns from reservoir surveys, the studies conducted by Borland 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

Fig. 6. Borland's stable channel stability relationship illustrated by James Vitaliano, Bureau of Reclamation, in 1960

Fig. 7. Whit Borland in 1953 at pilot cut for channelization of Rio Grande near San Marcial, New Mexico

slope as a pivot point. This pivot point was identified as approximating the mean operating pool elevation for the reservoir (Shen 1971).

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 methods. The first 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 USBR reservoir surveys of 6.5 times the topset slope.

Preliminary studies by Borland in April 1963 were made on the delta formation for design of a pumping plant on the Bill Williams arm of Lake Havasu for the Central Arizona Project. After sediment surveys in 1963, 1964, and 1970, a detailed study on delta development and projection for 150 years was made by Pemberton (1970), which describes the basis used in the design of dikes and inlets to the Central Arizona Pumping Plant at Lake Havasu on the Colorado River above Parker Dam.

With the trapping of sediment in a reservoir accompanied by clear water releases, downstream channels were no longer stable and were subject to bank and bed erosion. Reservoir surveys or special surveys were made by the USBR under Borland's direction for defining the degradation downstream from a dam. A study on downstream degradation was made for the Colorado River below Glen Canyon Dam with the results presented in an unpublished study by Miller and Borland (1957). A follow-up report made during the construction of Glen Canyon Dam was described by Borland (1960a,b). In September 1953, a study was undertaken in 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. A study on the upstream aggradation and downstream degradation at Milburn Diversion Dam based on surveyed channel cross sections in 1961, 1964, and 1967 was made by Strand (1968).

Design of Diversion Dams for Sediment Exclusion

One aspect of Borland's experience in the Sedimentation Section was his continued interest in the bureau's construction projects. One of the most intriguing problems 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 USBR 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 the Imperial Diversion Dam on the Colorado River for diversion into the All-American Canal. Prior to the 1950s most diversions by private engineering companies, as well as the USBR, 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, which resulted in the diversion of the coarse-size bed material sediments.

Starting in the 1950s the USBR Hydraulics Laboratory conducted model tests of diversion structures described by Dominy (1966) for excluding the coarse sand and gravel from irrigation canals. The design features consisted of (1) water diversion at a concave bend by construction of a curved training wall, (2) diversion at a point of natural stream channel curvature, (3) use of an undersluice tunnel with the diverted water passing over the top of tunnel, (4) use of a grated drop inlet at the bottom of channel, and (5) modification to the vortex tube at the headwork's intake for bypassing the coarser bedload material.

Settling Basin Designs for Canals

Prior to the 1950s 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 ft/s. Sand or coarser material

(>0.0625 mm) 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 USBR prior to the late 1960s was described in the report by Vetter (1940). In the late 1960s the Sedimentation Section began an investigation on the design of settling basins under the direction of Borland, which resulted in the report for sizing settling basins by Pemberton and Lara (1971). This report summarized the technique by Vetter with the method developed by Einstein (1965). 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.

River Bed Scour

Scour of a riverbed during a major flood event was an important design feature for the USBR at channel bankline structures and in the use of siphons for a canal crossing. A joint effort by Lane and Borland (1954) concluded that during floods the riverbed will scour at the narrow sections and this scoured material will be deposited at the next wide section downstream. On rivers such as the Rio Grande there is no general lowering of the riverbed as evidenced by lack of sediment deposits in the downstream Elephant Butte Reservoir. The paper illustrates the variations in scour occurring at narrow sections or at bridge sections with piers based on 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 by Jarecki (1959).

Concluding Remarks

From 1950 until 1970, Whit Borland was responsible for guiding the sediment program for the USBR, and in 1972 he received the Department of Interior's Meritorious Service Honor Award for his contribution in river channel hydraulics. He was a man of vision, and as a professional engineer was responsible for development of new procedures in sedimentation engineering. He undertook new challenges and was always striving for updating the sedimentation investigations and responsibilities in the USBR. He encouraged and actively took part in the preparation of professional papers. He left a legacy in the hydraulic engineering profession by developing procedures for predicting distribution of sediment in reservoirs, evaluating stability of natural river channels, and defining construction techniques used in stabilizing river channels. His work with E. W. Lane resulted in his design of the illustration of the balance scale in a qualitative relationship for defining problems in stream morphology.

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