DR. GEORGE W. ANNANDALE, PE

Education

BSc, Civil Engineering, University of Pretoria

MSc, Civil Engineering, University of Witwatersrand

DIng, Civil Engineering, University of Pretoria

Languages

English – Fluent

Afrikaans – Fluent

German – Conversational

French – Elementary

Spanish – Elementary

Dr. Annandale is a distinguished Civil Engineer with over 50 years of specialized experience in **water resources engineering**. His profound contributions to the field have earned him international recognition, including being named by *Water Power and Dam Construction* as **one of 20 engineers who made a significant international contribution to dam engineering**. He was honored with the **Lifetime Achievement Award** by the **United States Society of Dams** in 2022 and recognized as an **Honorary Member of ICOLD** in 2025 for his global impact on Dam Safety and the Sustainable Development of Dams and Reservoirs.

Dr. Annandale is renowned for developing the **Erodibility Index Method**, a globally accepted standard for determining the erodibility of earth materials, including rock formations. This method is widely adopted for the design and safety assessment of dams and other water infrastructure, featured in manuals and guidelines by organizations such as the U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Federal Highway Administration, Federal Energy Regulatory Commission, Electricité de France, and numerous U.S. state transportation agencies. He is the author of the seminal book, *"Scour Technology"* (McGraw-Hill, 2006), which serves as a standard reference in this specialized field.

His expertise further extends to **reservoir sedimentation management**, having led numerous projects worldwide. He has authored and co-authored four books on this subject and co-developed the **RESCON 2 software** for the World Bank. RESCON 2 is utilized at the appraisal level to identify optimal reservoir sedimentation management approaches by assessing technical feasibility, conducting economic optimization, evaluating intergenerational equity potential, and analyzing the impact of climate change uncertainty on preferred methods.

As a respected member of **Dam Safety Panels of Experts** for major projects, including Rogun Dam (Tajikistan), Dasu Dam (Pakistan), and Kariba Dam (Zambia), Dr. Annandale provides critical oversight as a hydraulics expert and specialist in scour and reservoir sedimentation management. His extensive global experience in water resource projects includes a comprehensive World Bank study on the hydrologic, economic, and institutional aspects of dam development in Kenya, and contributions to dam and hydropower development in the Mekong River Basin as a consultant for the Mekong River Commission and the governments of Vietnam, Laos, and Cambodia. Dr. Annandale consults internationally, with project experience spanning over 25 countries.

PROJECT EXPERIENCE

Ituango Dam Tunnel Failure Colombia

The Ituango Dam, owned by Empresas Públicas de Medellín (EPM), is a 225m high embankment dam constructed in the Cauca River near Ituango in the Antioquia Department, Colombia. Between 28 April and May 7, 2018 the tunnel was blocked by rock slides within the tunnel, which resulted in the formation of a large sinkhole along the right side of the tunnel that reached the surface. The blockage of the tunnel resulted in water rapidly filling the reservoir, threatening to overtop the dam. Dr. Annandale was commissioned to assess the failure and determine its cause. The tunnel floor was unlined, while the sides and roof of the tunnel were protected with shotcrete. The investigation entailed investigating the geology, assessing its scour threshold and comparing it with the erosive capacity of water that flowed through the tunnel.

Embalse Punchina Reservoir Sedimentation Colombia

ISAGEN, the owner of Embalse Punchina commissioned the Consultant, WSP Colombia, to conduct a Feasibility Study (FS) and Environmental Impact Assessment (EIA) for the selection of the preferred sedimentation management strategy at the dam. Dr. Annandale is a senior reviewer overseeing the studies for the selection of an optimal reservoir sedimentation management strategy.

Rogun Dam
Tajikistan

Dr. Annandale serves on the Dam Safety Panel of Experts as Hydraulic Engineering Expert for Rogun Dam. Responsibilities include review of overall flood management, checking of conformance of hydraulic structures to international best practice, review of spillway layout and design, including design of energy dissipation facilities, plunge pool design, review of physical hydraulic model studies, overall review of construction plans related to hydraulic structures, monitoring, and reservoir sedimentation management.

Oroville Spillway Incident
California

The service spillway of Oroville Dam failed on February 7, 2017 and severe scour damage occurred downstream of the emergency spillway when it was activated on February 12, 2017. Dr. Annandale was commissioned by FERC to assist with emergency measures to stabilize the remainder of the service spillway and harden the area downstream of the emergency spillway, and to execute a forensic assessment of the failure.

Oroville Spillway Emergency Spillway Erodibility Analysis
California

As Senior Reviewer to BGC Engineering evaluated the potential for scour initiation downstream of the emergency spillway's (ES) roller compacted concrete (RCC) apron/secant pile wall (SPW) that could lead to head-cut migration, undermining of the ES control section, and uncontrolled reservoir release. This was achieved through the development of a 2D probabilistic time-rate of scour model for the ES RCC/SPW region.

Lined Spillway Risk Analysis Tool Box USA

Preparation of a toolbox to assess the risk of spillway failure for the U.S. Army Corps of Engineers' dam safety program. Work entailed development of methods to assess hydraulic jacking in spillway channels and energy dissipators, quantification of the effects of ball-milling, headcut erosion, relative rate of headcut erosion, plunge pool and overtopping scour and safety assessment, cavitation potential, and scour downstream of conduit outlets.

Kariba Dam Zambia	Dr. Annandale serves on the Dam Safety Panel of Experts for the stabilization of the plunge pool downstream of Kariba Dam and replacement of six spillway gates. Since commissioning in 1960 a plunge pool of about 270ft (90m) was scoured in gneiss downstream of the dam. The plunge pool will be stabilized by increasing the size of the pool per a design based on extensive physical and computer model studies. The replacement of gates is necessary because of alkali-silica reaction (ASR), which resulted in misalignment of the guides.
FERC Guidelines USA	Dr. Annandale has been commissioned by the Federal Energy Regulatory Commission to revise the technical guidance facilitating evaluation of the risk of dam failure due to rock erosion, contained in FERC's "Engineering Guidelines for the Evaluation of Hydropower Projects" Dam Safety Guidelines.
Lower Baker Dam Washington State	Dr. Annandale serves as a sub-consultant to Shannon & Wilson on relicensing of Lower Bake Dam, owned by Puget Sound Energy. His responsibility relates to assessing rock scour potential and extent in the plunge pool and abutments.
Lost Creek Dam California, USA	Lost Creek Dam is a 122 ft high concrete arch dam, built in the 1920s. The dam is predicted to overtop by about 10 ft during PMF conditions. The project entailed a hydraulic and scours analysis to determine the anticipated scour extent downstream of the dam. About 20 ft of scour in the serpentized peridotite rock is predicted and conceptual designs for mitigating its effects were prepared.
Bull Run No. 2 Oregon, US	Dr. Annandale was commissioned by the City of Portland Water Bureau to perform a rock scour analysis at Bull Run No.2 Dam, forming part of the city's water supply system. Scour in rock was previously observed downstream of the spillway when a flood of 25,100cfs occurred in 1965. A geologic investigation indicated that the site was characterized by various basaltic flows, with some weaker flows underlying stronger ones. The analysis indicated that if a stronger basaltic layer would experience scour that the scour hole will dramatically increase in depth once the weaker layer below is removed by the erosive capacity of the flowing water.
Cabinet Gorge Dam, Spillway Stability Idaho, USA	Assessment of Erodibility of rock for Cabinet Gorge Dam, Washington Water Power. Emergency spillway is constructed of in natural rock. Assessed rock properties, determined erosive capacity of water and used Erodibility Index Method to determine spillway stability.
Comanche Dam, Mokolumne River California, USA	The planned Folsom South Canal pipeline for East Bay Municipal Utility District crossed the Mokolumne River directly downstream of the Comanche Dam spillway outlet. It was necessary to determine how deep scour would be and whether it would adversely affect the pipeline crossing. The project entailed analysis of rock scour at confluence between spillway flows form Comanche Dam and Mokolumne River to determine scour depth and subsequent required depth of the pipeline crossing.
Scour Analysis, Dunsmuir Reservoir California, USA	Scour analysis for Dunsmuir Reservoir under seismic conditions, for East Bay Municipal Utility District.

Eagle Nest Dam
New Mexico, USA

Eagle Nest Dam was constructed in 1917 and consists of a 146 ft high arch dam. Project entailed hydraulic and scour analysis to assess scour potential due to overtopping floods of 13 ft depth onto a gneiss rock foundation. Development of mitigation measures by modification of the dam crest to break up the overtopping jet by means of Roberts splitters. Executed a physical hydraulic model study to determine mitigation design effectiveness. Project also utilized LiDAR to map rock discontinuities.

Bartlett Dam
Arizona, USA

The Bureau of Reclamation commissioned Dr. Annandale, as part of a dam safety investigation, to assess scour of rock in the plunge pool of Bartlett Dam, Salt River Project. 33 m of scour in granite occurred during a flood of 100,000 cfs. Project entailed application of the Erodibility Index Method to assess stability of mitigation designs.

Earth Dam Breach Modeling
Arizona, USA

The project entailed development of software code that can simulate the extent and timing of dam breaches that could develop in earth embankments. The work was executed for Maricopa County Flood Control District, Phoenix and addressed dam breach scenarios commencing with vertical cracks in embankments, round openings in the embankments (piping) and in vertical filters, and failure initiation by flow through deep-seated fissures in the foundation underneath the earth embankments. The time to breach and the overall extent is important as it has significant economic impact and raises public safety concerns downstream of the county's flood control dams.

Gross Dam
Colorado, USA

The Gross Dam and Reservoir is an important component of Denver Water's water supply system, which serves 1.4 million people in the Denver-metro area. The 340 feet high concrete gravity arch dam will be increased in height to increase its storage space and thereby increasing water supply reliability to Denver Water customers. As part of the investigation, Denver Water requested Dr. Annandale to perform a rock scour analysis.

Reuter Hess Dam,
Colorado, USA

Dr. Annandale was commissioned to conduct a scour review of the spillway of Reuter Hess Dam, Colorado. The spillway is located in the Upper Dawson Formation, principally consisting of moderately weathered sandstone and claystone with slicken-sided fracture surfaces. Dr. Annandale conducted an analysis to estimate the potential for headcutting and its rate of progression, and the effectiveness of soil-cement protection to prevent such scour.

Bluestone Dam
West Virginia, USA

Bluestone Dam is a 200 ft high gravity dam with a energy dissipater spillway. The project entailed assessing the scour of rock just downstream of the spillway section and downstream of six modified penstocks intended for use as an emergency spillway. The spillway design flood increased from 490,000 cfs to more than 1,000,000 cfs since construction in 1940. The U.S. Army Corps of Engineers, owner of the dam, opened the penstocks that were never fitted with turbines to use as emergency spillway. An assessment of rock scour was required to determine the effect of large flood releases on dam stability should rock scour downstream of the dam remove passive rock wedges. New techniques were developed to determine scour of rock downstream of penstock outlets. The remaining energy dissipater flood also exceeds the design flood, causing extensive scour of rock in the immediate reach downstream of the dam.

Smith Mountain Dam Virginia, USA	Dr. Annandale executed a scour analysis to determine the potential and extent of scour of the foundation of Smith Mountain Dam. The 235 ft high double-curvature arch dam is expected to overtop under PMF conditions. The study determined whether the dam foundation consisting of rock will scour under such conditions, and if it would, to what extent. The analysis included fatigue analysis to determine whether the concrete in the spillway chutes would fail under such flow conditions. The analysis entailed implementation of Annandale's Erodibility Index Method and the Comprehensive Fracture Mechanics (CFM) approaches.
Skiatook Dam Ancillary Spillway, Scour Analysis Oklahoma, USA	As part of a dam safety assessment Dr. Annandale was requested the US Army Corps of Engineers to perform a scour analysis on the ancillary spillway of Skiatook Dam. The ancillary spillway is unlined in natural rock.
Potassi Dam, Spillway Scour Assessment Missouri, USA	Assessment of scour of earthen spillway of Potasi Dam. Dresser Industries. Original spillway constructed as a grass-lined earth material facility. Design was changed to a concrete lined spillway with energy dissipater due to failure potential of original spillway.
Solomon Gulch Dam, Spillway Stability Alaska, USA	Assessment of spillway stability and erosion of rock. Spillway constructed in natural rock. Used Erodibility Index Method to assess spillway stability and potential for uncontrolled releases.
Muskrat Dam, Canada	The 824MW Lower Churchill Management Corporation commissioned Dr. Annandale to review the design of the spillway chute channel for Muskrat Dam, particularly as it relates to potential scour of rock of the unlined portion of the spillway channel. Muskrat Falls is equipped with two spillways: a primary five vertical gates over rollways spillway; and a secondary free overflow crest spillway. The primary spillway will serve as a temporary diversion during the construction of the overflow dam and the powerhouse. The client desired to determine whether not lining the downstream portion of the spillway, as a money saving measure, would endanger the dam during the construction and once in operation. Dr. Annandale performed an independent analysis, discussed the results with the client and the client's engineer, and made recommendations.
Karahnjukar Dam Iceland	Dr. Annandale acted as an expert on the design of the spillway plunge pool area for the Karahnjukar project in Iceland. The spillway discharges water on an annual basis into a canyon that is 100 m deep by 60 m wide, consisting of rock. The bed of the canyon is expected to scour under these conditions. The project participation involved analysis of rock scour potential, execution of physical hydraulic model studies, and design of mitigation measures.
Paradise Dam, Australia	Paradise Dam is a 121ft high RCC dam commissioned in 2005, in the Burnett River, Queensland, Australia. It experienced two significant floods soon after commissioning, one in 2010 (~310,000cfs) and one in 2013 (~600,000cfs). Damage was recorded in 2010, with major rock scour occurring in 2013. Rock scour 7m (21ft) deep occurred immediately downstream of the spillway, with undercutting of the spillway having developed in some of the reaches along the endsill. Dr. Annandale was commissioned to conduct a forensic investigation for the insurance companies requested to pay for the damage.

Boondooma Dam, Australia	Dr. Annandale, working with Dr. Mike Marley, was commissioned to provide expert opinion regarding the claim made by the owner of Boondooma Dam after sever rock erosion occurred during the 2010-2011 flood. The dam was originally constructed in 1983 and progressive scour of rock in an unlined spillway commenced soon after commissioning, resulting in a vertical rock face of about 30m (120ft) at the current end of the spillway.
Hinze Dam Australia	As part of the Stage 3 upgrade of Hinze Dam, Dr. Annandale directed work to assess the performance of the lined spillway, the energy dissipater and plunge pool at the downstream end of the spillway, unlined rock stilling basin walls, the potential effects of overtopping flows on the dam left abutment and potential for scour at the dam toe.
Eildon Dam Australia	Eildon Dam supports an AUS$5 billion economy and was subject to a dam safety inspection and upgrade. Dr. Annandale was requested to review work executed by the consultant, to assess the failure potential of the lined concrete spillway and energy dissipater, and to determine the potential for rock scour of the spillway foundation. The assessment indicated anticipated spillway lining failure and significant scour of the underlying sedimentary rock foundation. Conceptual mitigation designs were prepared to protect the dam against breaching and the potential for uncontrolled releases. The participation included observing physical model studies and advising on measures that can be taken to improve flow conditions and minimize the risk of failure of the spillway chute, rock foundation and dam.
Salt Creek Pipeline Scour Assessment California, USA	Investigation to quantify the short, medium and long term scour that can be experienced at a sewer line and development of designs to protect the sewer against breakage by scour. Project executed for the Metropolitan Water District of Los Angeles.
Scour Analysis, Woodrow Wilson Bridge Maryland	The riverbed at the new Woodrow Wilson Bridge to be constructed over the Potomac River consists of a combination of very soft and very stiff clay. The Erodibility Index Method, developed by Dr. Annandale, was used to assess the scour in both the very soft and very stiff clays, which is currently the only practical approach available to assess the Erodibility of any earth material. The estimated savings accomplished at the Woodrow Wilson Bridge at the piers where the Erodibility Index Method was used to determine the founding depth was $20 million.
Scour Analysis, Folsom Bridge, American River California, USA	Scour analysis for Folsom Bridge, American River. The Folsom Bridge is founded on erodible rock in an expansion just downstream of a canyon. A two-dimensional finite element model was used to analyze the hydraulics at the bridge and calculate the erosive power at the bridge piers.

Northumberland Strait Bridge, Scour
Canada

Dr. Annandale provided consulting services to the design team of the Northumberland Strait Bridge, connecting mainland Canada to Northumberland Strait Bridge. The bridge is founded on sedimentary rock in some locations and on glacial till in others. Some of the bridge piers experienced scour in the sedimentary rock during a severe storm that occurred during construction. The scour observed at these piers was used to confirm the erosion threshold line of the Erodibility Index Method, developed by Dr. Annandale. The design team subsequently used the Erodibility Index Method to design the foundations of the remainder of the bridge. A real-time monitoring system, based on the Erodibility Index Method, is currently used to monitor the performance of the bridge during storm conditions.

Scour of Rock Around Bridge Piers
Colorado, USA

Development of a method to predict scour of rock around bridge piers, in cooperation with the Federal Highway Administration. Research findings are presented in a Scour Manual developed for the Colorado Department of Transportation.

Development of Erodibility Index Method
USA

Development of a method to predict scour of any earth material, including rock, vegetated soils, cohesive soils and non-cohesive granular material.

Total Oil Company, Pipeline Scour and Protection
Indonesia

Investigation to determine causes of pipeline scour and design protection for oil and gas pipelines owned by the TOTAL oil company in the Mahakam Delta, Kalimantan, Indonesia. The Mahakam Delta is one of the largest river deltas in the world. Extensive fieldwork and design resulted in cost-effective designs to protect exposed pipelines against damage. Investigations were executed and remedial designs prepared for ten river crossings in the delta.

Scour Analysis: Colorado River Aqueduct
California, USA

Dr. Annandale was retained by the Metropolitan Water District of Southern California to conduct a scour analysis on the Colorado River Aqueduct where it crosses the Whitewater River close to Palm Springs. The Colorado River Aqueduct provides 40% of the water supply needs of Southern California.

Global Reservoir Sedimentation and Sustainable Development Project

World Bank

Dr. Annandale was a senior member of the World Bank project on developing policy and practical tools promoting sustainable development of dams and hydropower projects through reservoir sedimentation management. He was the principal author of the book “Extending the Life of Reservoirs” that explained the design principles for accomplishing sustainable development of dams and hydropower facilities through reservoir sedimentation management. He was also the principal author of Sustainable Development Policy Guidelines published by the World Bank to guide countries and utilities on the sustainable development of dams and reservoirs by implementing system-wide reservoir sedimentation management practices. The third component, i.e., development of practical tools for analysing and identifying technically viable and economically optimal reservoir sedimentation management approaches at pre-feasibility level, which also provided a decision-making technique on dealing with the uncertainty associated with climate change was conceptualized by him. This resulted in the development of the RESCON 2 software under his senior review.

Sediment Management
Mekong River

Dr. Annandale developed alternative conceptual designs for existing and proposed dams in Vietnam, Laos and Cambodia promoting passage of sediment to maintain the geomorphology of the Mekong River, Mekong Delta and Tonle Sap. This project provided insight into sediment transport and fluvial geomorphologic features of the Mekong River.

Xayaburi Dam Sedimentation
Mekong River

Xayaburi Dam is a 1,285MW hydropower facility, the first proposed dam in the main stem of the Lower Mekong River. Dr. Annandale was responsible for determining the impact of the Xayaburi Dam on the sediment balance of the Mekong River, appointed by the Mekong River Commission to provide information for the Consultation process required under the Mekong River Agreement. He recommended installation of large, low-level radial gates for managing sediment in the reservoir and for passage downstream.

MDS Study
Mekong River
Vietnam

Dr. Annandale was an expert on the Mekong Delta Study (MDS) Commissioned by the Government of Vietnam in 2013 to determine the impact of proposed main stream dams on the Mekong River on the Mekong Delta in Vietnam. He participated in the study as a specialist in sediment transport and reservoir sedimentation management to the Danish Hydraulic Institute (DHI), consultant to the Government of Vietnam. His responsibilities included reviewing the sediment sampling conducted during the wet and dry seasons, review and comment on sediment transport modeling executed by DHI and provide advice on mitigation measures.

Kaps Dam
Dam Safety Panel of Experts
Armenia

Dr. Annandale serves on the Independent Panel of Experts for the construction of Kaps Dam, Armenia. The dam was partly constructed by the Soviet Union and abandoned in the 1980's during the collapse of the Union. His responsibilities entail reviewing hydrology and hydraulics, and the impact of climate change on project feasibility.

Alcona Dam
Dam Safety
Michigan

Dr. Annandale serves as a subject matter expert on a pilot study for applying the Risk Informed Decision Making (**RIDM**) process introduced by FERC as part of the relicensing process of the facility. The subject matter advised on by Dr. Annandale relates to hydraulics and scour of an auxiliary spillway in peat, with cattail growth. Embankment erosion by wave action and the effects of debris on dam safety has also been studied by him, and he was required to review detailed three-dimensional computer simulation of the spillway. In addition to advising on technical matters he also participated in the overall RIDM process as required by FERC.

Batoka Dam
Dam Safety Panel of Experts
Zambia / Zimbabwe

Batoka Dam is planned for construction just downstream of Victoria Falls, in the Batoka Gorge located along the Zambezi River. The current plan is to construct a RCC arch dam more than 100m high. Dr. Annandale serves on the Dam Safety Panel of Experts reporting to the Zambezi River Authority that is responsible for the development of this project, which will supply electricity to Zambia and Zimbabwe. Dr. Annandale's responsibilities deals with all aspects of hydraulics and hydrology, hydraulic structures and related dam safety issues.

Rusumo Falls Dam Safety Panel of Experts Rwanda

Rusumo Falls Hydroelectric Project forms part of the Nile River Basin Initiative and is located on Kagera River that originates in Burundi and forms the border between Rwanda and Tanzania at the project location. The project will supply power to Rwanda, Burundi and Tanzania. Dr. Annandale serves on the Dam Safety Panel of Experts reporting to NELSAP and is responsible for overseeing hydraulic design and hydrology.

Mount Coffee Dam Safety Panel of Experts Liberia

Mount Coffee Hydroelectric Project in Liberia was damaged during the civil war in that country. One of the radial gates became inoperable in open mode and the electro-mechanical equipment was removed from the power house. Dr. Annandale served on the Dam Safety Panel of Experts responsible for rehabilitation of the project and was responsible for the hydrologic assessment, sediment management and hydraulic design.

Tina River Dam Dam Safety Panel of Experts Solomon Islands

Dr. Annandale has been appointed on the Dam Safety Panel of Experts for the Tina River Dam, Solomon Islands as the expert on hydraulics, hydrology and sediment transport. The project faces several challenges, amongst other potentially severe reservoir sedimentation. Dr. Annandale will be advising on appropriate reservoir sedimentation management approaches, as well as reviewing design flood estimates and adequacy of spillway design.

Sambor Dam Conceptual Design Cambodia

Dr. Annandale prepared an alternative conceptual design for Sambor Dam, Cambodia. The dam is the most downstream proposed dam in the main stem of the Mekong River, raising concerns about its impact of the morphology of the Mekong Delta in Vietnam and its anticipated impact on the fishery, which is one of the most diverse fisheries in the world. The originally proposed Sambor Dam consists of a dam of approximately 11miles long (18km) with no fish passage. The originally proposed dam will capture a more sediment than all the other proposed upstream dams combined and is expected to severely impact the Mekong Delta, which provides sustenance to about 40 million people. The alternative dam design will generate about 60% of that from the originally proposed dam, will pass about 95% of the sediment and pass about 95% of the fish, and is found to be economically feasible.

Eildon Dam Dam Safety, Australia

Eildon Dam supports an AU$5billion economy and was subject to a dam safety inspection and upgrade. Dr. Annandale was requested to review work executed by the consultant, to assess the failure potential of the lined concrete spillway and energy dissipater, and to determine the potential for rock scour of the spillway foundation. The assessment indicated anticipated spillway lining failure and significant scour of the underlying sedimentary rock foundation. Conceptual mitigation designs were prepared to protect the dam against breaching and the potential for uncontrolled releases. The participation included observing physical model studies and advising on measures that can be taken to improve flow conditions and minimize the risk of failure of the spillway chute, rock foundation and dam.

Senior Review
Spillway Safety
Rock Scour
US and International

Dr. Annandale offers senior review services on numerous spillway assessments in the United States and Globally. Most of the spillway assessment projects are associated with rock scour or anticipated rock scour under design flood conditions. Projects he has been involved in include

- Tiger Creek Dam, California.
- Tarryall Dam, Colorado.
- Pyramid Dam, California.
- Tule River Dam, California.
- Goro Mine Dam, New Caledonia.
- Bull Run 1 Dam, Oregon.
- Lewisville Dam, Texas.
- Combie Dam, California.
- Don Pedro Dam, California.
- Butt Valley Dam, California.
- Philbrook Dam, California.
- North Battle Creek Dam, California.
- Lake Valley Dam, California.
- Round Valley Dam, California.
- Lake Fordyce Dam, California.
- Trail Bridge Dam, Oregon.
- Strawberry Dam, California
- McCloud Dam, California

Rhinedollar Dam
Dam Safety
Risk Review Board
California

FERC required relicensing of Rhinedollar Dam that is owned by Southern California Edison. The relicensing process entailed executing an **RIDM** to ensure the safety of the dam. The process entailed conducting a Potential Failure Mode Analysis and a Quantitative Risk Assessment (**QRA**). Dr. Annandale served on the Risk Review Board for the RIDM.

Hydropower Development: Master Plan
Xe Kong River, Laos

The purpose of the "Master Plan" is to assist the Government of Lao PDR in implementing the12 January 2015 Decree of the Prime Minister promulgating a Policy on Sustainable Hydropower Development in Lao PDR. This policy builds on the National Policy on Environmental and Social Sustainability of the Hydropower Sector in Lao PDR (June 7, 2005), in which the government of Lao PDR proclaims that hydropower development must be sustainable if its potential to deliver lasting benefits is to be fully realized and that ecological sustainability depends upon the avoidance of irreversible environmental impacts such as the loss of biodiversity or disruption of ecological cycles. The study will assess opportunities for siting future hydropower dams in locations that do not inundate or block fish passage into the habitats that are most valuable for migratory fish breeding and rearing; for designing the dams to efficiently pass sediments and nutrients; and for operating the dams to maintain enough natural variability of flow patterns to enable the fish to access the high-value habitats

Don Sahong Dam
Mekong River

Dr. Annandale prepared the sediment impact assessment for the proposed Don Sahong Dam under commission from the Mekong River Commission, as part of the Consultation process required under the Mekong River Agreement signed by Vietnam, Thailand, Cambodia and Loas.

Sediment Transport Modelling
Papua, Indonesia

Dr. Annandale modelled sediment transport and directed studies over a period of 16 years to simulate sediment deposition and transport in a river that is 60km long and 4 to 9km wide, and is subject to excessive sediment loads. The software that has been used on this project during its 10-year history include HEC-6, MIKE 11 and MIKE 21C. Information is used for planning levee designs for public safety and for environmental impact assessment. The levees protect a community of about 300,000 people and critical infrastructure against floods.

Design Flood Estimation
Papua, Indonesia

Determination of the heights of levees required quantification of the Probable Maximum Flood. The challenge was that very little site specific data was available. Dr. Annandale collected maximum flood peak data throughout the Indonesian archipelago and from Papua New Guinea to develop a regional hydrologic analysis. The analysis is based on the Francou-Rodier approach, providing an experience-based, defensible estimate of the maximum flood.

Silver Lake Dam Failure, Forensic Investigating Expert,
Michigan

An upgrade completed in 2002 at Silver Lake Dam included construction of a fuse-plug for management of the PMF. The fuse-plug was pre-maturely activated in 2003 and resulted in an uncontrolled release that emptied the reservoir and resulted in damages exceeding $100million. Dr. Annandale acted as an expert, investigating the causes of the Silver Lake Fuse Plug failure, advising legal counsel.

Pipeline Scour Assessment
Kalimantan, Indonesia

TOTAL, a French oil company, has extensive operations in the Mahakam Delta in Kalimantan. The oil pipelines criss-crossing the delta pass underneath numerous rivers. Exposure of one of the pipelines, due to the effects of scour resulted in a fatality when it exploded. Dr. Annandale assessed all the pipeline crossings for scour potential and made recommendations to protect the pipelines against the effects of scour.

River Restoration Design
Sumbawa, Indonesia

During the construction of the Bata Hijau Mine on the island of Sumbawa the contractor excavated gravel from the inside of meander bends in the river, causing significant scour and river degradation. The mining company required the contractor to restore the rivers to their original condition, thereby reducing the sediment load of the river to the ocean. Dr. Annandale prepared designs to restore the rivers and reduce their sediment loads.

Sedimentation: Kouaoua River
New Caledonia

The mouth of the Kouaoua River in New Caledonia is subject to severe sedimentation due to the effects of nickel surface mining on the island. The sedimentation causes severe flooding of the town located at the mouth of the river. Dr. Annandale developed approaches to reduce sedimentation at the river mouth, thereby reducing flooding potential of the town.

Reservoir Sedimentation
Lower Mekong River Basin

The morphology of the Lower Mekong River, Mekong Delta and Tonle Sap will be significantly affected by the planned construction of about 130 dams in the Lower Mekong River Basin. Dr. Annandale directs a project developing alternative designs for the projects, allowing increased sediment passage while concurrently minimizing the amount of hydropower that may be generated by these dams. The project entails influencing water resource development policy, requiring meetings with senior ministers, government officials and senior officials of hydropower development companies in Vietnam, Laos, Cambodia and China.

RESCON Project
Worldwide

Development of the Life-Cycle Management Approach for sustainable management of surface water reservoirs and software to determine the technical feasibility of optional sediment management techniques and identification of the optimal economic management approach. Project executed for the World Bank.

Santa Ana River Bed Coarsening Investigation
California

Prado Dam, located in the Santa Ana River in California affected sediment discharge in the downstream river reach. The dam commands 87% of the entire Santa Ana River basin and traps 95% of inflowing sediment. The Orange County Water District have managed the aquifer underlying the Santa Ana River since 1927 by encouraging infiltration through the Santa Ana River bed. In recent years it has been found that the permeability of the river bed decreased. Dr. Annandale directed an investigation into how the grain size distributions of the bed material changed with time. It was found that the shape of the size distribution curve of the bed material explained the decrease in permeability, in spite of bed material coarsening.

Tarbela Dam Reservoir Sedimentation
Pakistan

Dr. Annandale executed the fifth periodic inspection of Tarbela Dam. The Government of Pakistan commissions periodic inspections of Tarbela Dam to ensure its safety and to monitor reservoir sedimentation. Dr. Annandale was responsible for assessment of the current state of reservoir sedimentation in Tarbela Dam and to identify approaches by which the facility can be managed in a sustainable manner. The inspection included assessment of the technical feasibility of varioius sediment management techniques and performance of an economic analysis to identify optimal sediment management approaches and the impact of Basha Dam, currently under construction upstream of Tarbela Dam, on its performance.

Reventazon Dam Sediment Management
Costa Rica

Dr. Annandale is currently directing a study for the development of designs to manage sediment at Reventazon Dam, Costa Rica. The concrete-faced rockfill dam (CFRD) will be located in very steep reaches of the Reventazon River, with high suspended and bedloads. Particular attention is directed at joint operation of the Reventazon Dam with two existing upstream dams, i.e. Cache and Angostura Dams that are flushed on an annual basis.

Strontia Springs Dam Sedimentation
Denver, Colorado

Dr. Annandale is currently working on the development of guidelines for long-term reservoir sedimentation management approaches at Strontia Springs Dam. The dam is owned by Denver Water and has been subject to significant loss of storage due to sedimentation resulting from increased sediment yield due to a large forest fire in its catchment. The sediment is currently removed from the reservoir by dredging, at very high cost. Denver Water wishes to develop more economic long-term sediment management strategies to prevent future storage loss.

Removing Barriers to Sustainable Hydropower Development
South Asia

Dr. Annandale directed a team commissioned by the World Bank to develop strategies for the removal of barriers to sustainable hydropower development in South Asia. One of the principal elements preventing sustainable development of hydropower in South Asia is loss of power generation capabilities due to the effects of sediment, which includes reservoir sedimentation and abrasion damage to turbines and civil infrastructure. The study entailed visiting eight projects in India and Nepal and investigating the adverse effects on project sustainability due to the high sediment loads in Himalayan Rivers.

Mahaweli System Reservoir Sedimentation
Sri Lanka

Dr. Annandale directed a study to develop a sediment management approach for the Mahaweli System of Reservoirs in Sri Lanka. The study entailed identifying economically optimal and technically feasible sediment management techniques for system reservoirs. The analysis was conducted by developing a system model that could identify coordinated sediment management approaches. In addition to the technical and economic analysis, reservoir surveys were performed to determine the amount of deposted sediment in key reservoirs.

Yanacocha Reservoir Sedimentation
Peru

Dr. Annandale directs regular reservoir sedimenation surveys executed on the Yanacocha Mine, Peru. Large dams were built to control sediment generated by the Yanacocha Mine. Surveys are conducted to determine the effectiveness of the sediment detention facilities and to quantify sediment yield from the mine property

Strontia Springs Reservoir Sedimentation
Colorado, USA

Dr. Annandale performed studies to identify economically optimal and technically feasible methods for managing sediment in Strontia Springs Reservoir that is owned by Denver Water, Colorado. The dam, which is part of the City of Denver's water supply system, was severely affected by sedimentation after the Buffalo Creek forest fire in 1995. In additional to assessing the technical and economic feasibility of sediment management, environmental impact was also considered.

Peligre Dam Reservoir Sedimentation
Haiti

Dr. Annandale worked assessment of reservoir sedimentation management options for Peligre Dam, Haiti. The project objective was to determine the economic feasibility of adding new turbines to the power generating capacity of the dam. Dr. Annandale's role was to identify economically optimal and technically feasible reservoir sedimentation management techniques to sustain reservoir performance.

Reservoir Sedimentation Management Policy
Morocco

Execution of an investigation at national level to determine the technically feasibility of managing sediment in Moroccan reservoirs, and to identify the optimal economic solutions to the problem. Morocco is a dry country that receives the bulk of its water supply from surface water reservoirs. The high sediment load in the country’s rivers deposits in the reservoirs, resulted in storage loss and subsequent reduction in the reliability of water supply. The project was aimed at prioritizing reservoirs and identifying economically optimal methods to manage sediment and ensure sustainable use of water resources and infrastructure.

Katse Dam, Sedimentation, Lesotho Highlands Water Project
South Africa

Dr. Annandale performed a reservoir sedimentation simulation study to locate the intake towers for Katse Dam. The project entailed development of software to simulate reservoir sedimentation.

Welbedacht Dam, Physical Hydraulic Model Study and Simulation
South Africa

Dr. Annandale was commissioned by the Department of Transporation, Orange Free State, to determine required bridge geometry for a bridge over the Caledon River that was subject to sedimentation from Welbedacht Dam. The study entailed executing sediment transport simulations by computer modeling and verifying results using a physical hydrauilc model study. Prediction of stable sediment profile due to reservoir sedimentation was determined for use in setting bridge geometry over the river.

Collywobbles Dam and Hydroelectric Facility Sedimentation
Africa

Dr. Annandale provided litigation support pertaining to rapid sedimentation of a hydro-electric facility in the former Transkei, South Africa. The work entailed review of designs, computer simulation and execution of physical hydraulic model studies to determine the effectiveness of low level scour gates.

Prado Dam Reservoir Sedimentation
California, USA

Pre-feasibility analysis to optimize sediment management techniques for sustainable management and use of Prado Dam and Reservoir. The analysis considered flushing, dredging and dry excavation and identified the most economical technique that will result in sustainable reservoir management.

Cogswell Dam and Reservoir, Reservoir Sedimentation Management
California, USA

Cogswell Dam is located in the San Gabriel River upstream of Los Angeles, acting as a flood control facility. The dam and its reservoir has been subject to severe sedimentation. The County of Los Angeles Department of Public Works commissioned Dr. Annandale to investigate flushing potential at the dam. The project entailed executing flushing operation simulation using HEC-6 software, development of operating rules for flushing, and presentation and defense of study results at public meetings.

Bluestone Dam Dam Safety, West Virginia

Dr. Annandale served as an expert consultant on the 156ft high Bluestone Dam. The project entailed assessing the scour of rock just downstream of the spillway section and downstream of six modified penstocks intended for use as an emergency spillway. The spillway design flood increased from 490,000cfs to more than 1,500,000cfs since construction in 1940. The US Army Corps of Engineers, owner of the dam, opened the penstocks that were never fitted with turbines to use as emergency spillway. An assessment of rock scour was required to determine the effect of large flood releases on dam stability should rock scour downstream of the dam remove passive rock wedges. New techniques were developed to determine scour of rock downstream of penstock outlets. The remaining energy dissipater flood also exceeds the design flood, causing extensive scour of rock in the immediate reach downstream of the dam.

Earth Dam Breach Assessment Dam Safety, Arizona

The project entailed development of software code that can simulate the extent and timing of dam breaches that could develop in earth embankments. The work was executed for Maricopa County Flood Control District, Phoenix and addressed dam breach scenarios commencing with vertical cracks in embankments, round openings in the embankments (piping) and in vertical filters, and failure initiation by flow through deep-seated fissures in the foundation underneath the earth embankments. The time to breach and the overall extent is important as it has significant economic impact and raises public safety concerns downstream of the county's flood control dams.

Comanche Dam, Mokolumne River California, USA

The planned Folsom South Canal pipeline for East Bay Municipal Utility District crossed the Mokolumne River directly downstream of the Comanche Dam spillway outlet. It was necessary to determine how deep scour would be and whether it would adversely affect the pipeline crossing. The project entailed analysis of rock scour at confluence between spillway flows form Comanche Dam and Mokolumne River to determine scour depth and subsequent required depth of the pipeline crossing.

Cabinet Gorge Dam, Spillway Stability Idaho, USA

Assessment of Erodibility of rock for Cabinet Gorge Dam, Washington Water Power. Emergency spillway is constructed of in natural rock. Assessed rock properties, determined erosive capacity of water and used Erodibility Index Method to determine spillway stability.

Lost Creek Dam California, USA

Lost Creek Dam is a 122 ft high concrete arch dam, built in the 1920s. The dam is predicted to overtop by about 10 ft during PMF conditions. The project entailed a hydraulic and scours analysis to determine the anticipated scour extent downstream of the dam. About 20 ft of scour in the serpentized peridotite rock is predicted and conceptual designs for mitigating its effects were prepared.

Eagle Nest Dam New Mexico, USA

Eagle Nest Dam was constructed in 1917 and consists of a 146 ft high arch dam. Project entailed hydraulic and scour analysis to assess scour potential due to overtopping floods of 13 ft depth onto a gneiss rock foundation. Development of mitigation measures by modification of the dam crest to break up the overtopping jet by means of Roberts splitters. Executed a physical hydraulic model study to determine mitigation design effectiveness. Project also utilized LiDAR to map rock discontinuities.

Bartlett Dam Arizona, USA

The Bureau of Reclamation commissioned Dr. Annandale, as part of a dam safety investigation, to assess scour of rock in the plunge pool of Bartlett Dam, Salt River Project. 33 m of scour in granite occurred during a flood of 100,000 cfs. Project entailed application of the Erodibility Index Method to assess stability of mitigation designs.

Earth Dam Breach Modeling Arizona, USA

The project entailed development of software code that can simulate the extent and timing of dam breaches that could develop in earth embankments. The work was executed for Maricopa County Flood Control District, Phoenix and addressed dam breach scenarios commencing with vertical cracks in embankments, round openings in the embankments (piping) and in vertical filters, and failure initiation by flow through deep-seated fissures in the foundation underneath the earth embankments. The time to breach and the overall extent is important as it has significant economic impact and raises public safety concerns downstream of the county's flood control dams.

Gross Dam Colorado, USA

The Gross Dam and Reservoir is an important component of Denver Water's water supply system, which serves 1.4 million people in the Denver-metro area. The 340 feet high concrete gravity arch dam will be increased in height to increase its storage space and thereby increasing water supply reliability to Denver Water customers. As part of the investigation, Denver Water requested Dr. Annandale to perform a rock scour analysis.

Reuter Hess Dam, Colorado, USA

Dr. Annandale was commissioned to conduct a scour review of the spillway of Reuter Hess Dam, Colorado. The spillway is located in the Upper Dawson Formation, principally consisting of moderately weathered sandstone and claystone with slicken-sided fracture surfaces. Dr. Annandale conducted an analysis to estimate the potential for headcutting and its rate of progression, and the effectiveness of soil-cement protection to prevent such scour.

Bluestone Dam West Virginia, USA

Bluestone Dam is a 200 ft high gravity dam with a energy dissipater spillway. The project entailed assessing the scour of rock just downstream of the spillway section and downstream of six modified penstocks intended for use as an emergency spillway. The spillway design flood increased from 490,000 cfs to more than 1,000,000 cfs since construction in 1940. The U.S. Army Corps of Engineers, owner of the dam, opened the penstocks that were never fitted with turbines to use as emergency spillway. An assessment of rock scour was required to determine the effect of large flood releases on dam stability should rock scour downstream of the dam remove passive rock wedges. New techniques were developed to determine scour of rock downstream of penstock outlets. The remaining energy dissipater flood also exceeds the design flood, causing extensive scour of rock in the immediate reach downstream of the dam.

Skiatook Dam Ancillary Spillway, Scour Analysis Oklahoma, USA

As part of a dam safety assessment Dr. Annandale was requested the US Army Corps of Engineers to perform a scour analysis on the ancillary spillway of Skiatook Dam. The ancillary spillway is unlined in natural rock.

Potassi Dam, Spillway Scour Assessment Missouri, USA

Assessment of scour of earthen spillway of Potasi Dam. Dresser Industries. Original spillway constructed as a grass-lined earth material facility. Design was changed to a concrete lined spillway with energy dissipater due to failure potential of original spillway.

Solomon Gulch Dam, Spillway Stability Alaska, USA

Assessment of spillway stability and erosion of rock. Spillway constructed in natural rock. Used Erodibility Index Method to assess spillway stability and potential for uncontrolled releases.

Muskrat Dam, Canada

The 824MW Lower Churchill Management Corporation commissioned Dr. Annandale to review the design of the spillway chute channel for Muskrat Dam, particularly as it relates to potential scour of rock of the unlined portion of the spillway channel. Muskrat Falls is equipped with two spillways: a primary five vertical gates over rollways spillway; and a secondary free overflow crest spillway. The primary spillway will serve as a temporary diversion during the construction of the overflow dam and the powerhouse. The client desired to determine whether not lining the downstream portion of the spillway, as a money saving measure, would endanger the dam during the construction and once in operation. Dr. Annandale performed an independent analysis, discussed the results with the client and the client's engineer, and made recommendations.

PROFESSIONAL AFFILIATIONS

Fellow, American Society of Civil Engineers

Member International Association of Hydraulic Research

Member of U.S. Society of Dams

Member of the Dams and Planning Advisory Team, World Bank, 2001 - 2003

Member of ASCE Sedimentation Committee, 1993 - 1998

Member American Water Works Association

Listed in Marquis' Who's Who in the World

Listed in Marquis' Who's Who in America

Listed in Marquis' Who's Who in Science and Engineering

External Reviewer: Italian Ministry for Universities and Research

External Reviewer: National Science Foundation, United States of America

External Reviewer: Swiss National Science Foundation, Division of Physical Science and Engineering

Editorial Board: Journal of Hydraulic Research, IAHR 1985 - 2002

Founder Member: Water, Sediment and Erosion Research (WASER), China

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