Commission of Inquiry
PARADISE DAM

PARADISE DAM COMMISSION OF INQUIRY

Commissions of Inquiry Act 1950
Section 5(1)(d)

STATEMENT OF GLENN TARBOX

Name of Witness:	**Glenn Stuart Tarbox**
Date of birth:	[redacted]
Current address:	**C/- Stantec** **2353 130th Ave NE Suite 200, Bellevue WA 98005**
Occupation:	**Engineer**
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Statement taken by:	**Jonathan Horton QC and Jane Menzies, Counsel Assisting**

I **Glenn Stuart Tarbox,** Engineer, make oath and state as follows:

Background

1. I am Senior Vice President of Structural Engineering, Power & Dams at Stantec where I have been employed since 1997. I am responsible for senior technical advisory and reviews for major dam projects.

2. I hold a Bachelor of Science in Civil Engineering and have completed the academic requirements of a Master of Science in Structural Engineering and Hydraulics.

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3. A copy of my curriculum vitae appears at document number [**SUN.503.001.0615**].

4. I have worked for over 50 years as a civil and structural engineer in the design and construction of large concrete dams. I was involved in introducing roller compacted concrete (**RCC**) technology in the United States Bureau of Reclamation, as I discuss below. I have been involved in the design and construction of 6 major RCC dams.

Involvement on the Technical Review Panel

5. I started as a member of the Technical Review Panel (**Panel**) in about the middle of last year (2019). I was asked to participate particularly from the point of view of RCC technology.

6. I was involved with preparing the Technical Review Panel Report No 2 dated 23 September 2019 (**Report No 2**) and Technical Review Panel Report No 3 dated 9 December 2019 (**Report No 3**). I was responsible for writing certain portions of those reports that I submitted to my colleague, Peter Foster. Because Peter is often physically present in Australia, he has been the point of coordination with John Young for geology and me for RCC. He was the aggregator of most of the pieces coming in and pulling the reports together.

7. I wrote section 3.2 of Report No 2– "*Construction Photos and Site Visit Observations of Technical Consultant During Construction*". The opinions expressed in those parts of the reports are ones I honestly hold.

8. I did not take the lead in putting together section 2 of Report No 3 – "RCC Strength Review" – but I was involved with reviewing it and signing the report. I think Peter Foster probably wrote it. I agree in general with the opinions expressed in that part of the report.

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Development of RCC technology

9. I have been involved with RCC dam design and construction developments since the 1960s. Previously, concrete dams were built in independent vertical monoliths that were constructed alternately one high, the next one low, the next one high so that there was a stair-step pattern of monoliths across a canyon. Each monolith had to be formed on all sides. It took a lot of labour, a lot of time. The mixes were low to moderate slump concrete mixes that were delivered and dumped into the blocks. The monoliths were placed in successive blocks anywhere from 5 feet up to 10 feet (1.5 to 3.0m) in height. The concrete was placed within a block in 3 to 5 layers and had to be vibrated with very heavy vibrators to consolidate the material. All these steps took a lot of time and cost a lot of money.

10. It was a competitive world of dam building back in those days. Around the world, the people building embankment dams made of rock or soil had developed huge machines able to excavate and haul large quantities of material. They could complete dams more quickly than we were doing with concrete dams. There were fewer concrete dams being built.

11. I was a young engineer in the 1960s; in my early 20s. The leaders in concrete dam design saw this as a challenge and wrote some conceptual papers that were delivered at a conference in California in May of 1972. The conference was titled the "*Engineering Foundation Conference on Economical Construction of Concrete Dams*". Its purpose was to begin to gather information on how we could build dams faster and cheaper so that we were competitive with those building embankment dams.

12. Out of that came the initial and seminal ideas of RCC. That was about designing mixes that were not high slump. They were going to be very low slump so that you could

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deliver it in trucks, dump it and spread it with a bulldozer. The material would actually support the weight of bulldozers and then we would compact it rather than consolidate it, which is what vibration is. We would compact it using heavy vibratory rollers. This would be done from the left abutment to the right abutment. In other words, continuous two-dimensional construction in one-foot layers. We would not form all the monoliths and build them vertically anymore. We would just place the dam from left to right. We would start at the bottom and if you could go without ever stopping, that would be an advantage.

13. Throughout the 60s and 70s, a lot of research was done by the United States Army Corps of Engineers (**Corps of Engineers**) and the United States Bureau of Reclamation (**Bureau of Reclamation**). Mr Ernie Schrader was the leader for the Corps of Engineers. I led the effort with the Bureau of Reclamation. In other parts of the world, Mr Malcom Dunstan developed RCC placement philosophies as well.

14. Dr Schrader was a materials engineer and he pursued low paste mixes. Malcolm Dunstan pursued high paste mixes. When I was reviewing the published literature for information to draw upon when we started to design the Upper Stillwater Dam with the Bureau of Reclamation, I was taken with the high paste mixes espoused by Dr. Dunstan. To me, the material was more like traditional concrete and we were interested in the design of a concrete dam, not just a mass of material that was stabilised and cemented together with the addition of some cementitious material.

15. I knew Ernie Schrader very well and still know him today. I also know Malcolm Dunstan. I am a very close associate of his.

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16. In the early days, the low paste mixes were the mixes of choice. Early numbers of dams that were designed and constructed with low paste mixes outnumbered those that were done using the high paste mixes.

17. RCC has been around for upwards of 50 years now and there are some 800 of these dams around the world. Today, however, the high paste mixes outnumber the low paste mixes. The philosophy has swung away from low paste to high paste particularly for large RCC dams.

Differences between low and high paste mixes

18. A low paste mix does not contain a lot of water. When the layers are placed, they are bonded with a bedding mix over a part or all of the previous layer. The first lift is placed, and then bedding mortar, and then the next lift is placed and so on. In the beginning, the idea was to have the bedding mix from the upstream face to the downstream face and every layer was bonded to the previous one. There were proposals to reduce the percentage of bedding from the upstream face into the dam. Paradise Dam was one where this was done.

19. Thus, what holds an RCC dam together? In earlier types of concrete dams using conventionally vibratable concrete (CVC), the lift lines (individual block heights) were 5 to 10 feet in height (1.5 to 3.0 m). RCC lifts heights are typically placed every 12 inches (about 30 cm). With high paste mixes, the concept is that each new 12 inch layer is placed while the previous lift is still 'alive' (in other words it has not been sitting exposed for a long period of time and remains receptive to bonding with a new layer spread and compacted on top of it). If there is no delay between placement of the lifts, bedding mix not required in between the lifts. Delay is related to time and temperature. The elapsed time that concrete is exposed to heat and drying is defined by

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a parameter defined as degree hours and there are rules of thumb specifying allowable limits. If the allowable limits are satisfied, the next layer can be placed on top of previous lift with no bedding mix. Compaction of the fresh lift using a 10 tonne vibratory roller results in the fresh lift bonding to the previous lift.

20. With this approach to placing RCC, the only time where you would use a bedding mortar is if it is stood out overnight for 24 to 40 hours or you had an intentional shutdown where you had to start up again. Then there were prescriptive steps that you had to go through to refresh that old lift surface. You could blast with high pressure water jets to expose the aggregate of the old layer without undercutting the aggregate, then spread the bedding mix on top of that before placing the next lift on top. Barring any interruptions, bedding mix was not needed to be used.

21. Paradise Dam was built in successive 30cm layers with bedding mortar between each layer over a specified percentage or distance from the upstream face.

Proper practice

22. There are aspects in common between the philosophies associated with low and high paste RCC mixes.

Cleaning of the lifts

23. The foundation upon which the contractor starts to build an RCC dam and all successive lifts of RCC must be properly prepared. The surface must be absolutely clean. It must be cleaned of all loose impediments, all loose rock, all soil, dust, mud, etc. It must be washed using high pressure water, blow dried and/or vacuumed to remove free standing water. When ready to place material on the surface, the surface must be in a condition called 'saturated super-dry'. This essentially means that there is

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no freestanding water, but the surface remains damp. The rock or a previous lift should not cause moisture to be drawn out of the layer being placed by sapping water out of the new RCC. Sapping the RCC of its moisture can lower the water to cement ratio and lower the strength of the concrete. Thus, it is very important that the preparatory steps be done consistently, continuously, and correctly.

Curing of the lifts

24. Once a lift is placed, compacted and the surface is sealed – it is important that it be cured, not with a curing compound (because that is a bond-breaker) but with water to keep it wet. Evaporative cooling of the cure water helps to exhaust heat out of the placed RCC. Concrete has a property of RCC known as the 'adiabatic temperature rise' where the exothermal reaction of the chemicals in cement create heat. It is desirable to enhance the reduction in that temperature and enhance the evacuation of that heat. Water curing is an effective means of reducing the heat gain in fresh RCC. Water curing must be continuous. If the surface is allowed to dry out, the surface begins to form a layer which, if left too long, will actually not be conducive to bond with the next layer, whether referencing bedding mix or the RCC. Water curing must be applied uniformly, consistently, universally in all locations and throughout the entire construction period.

25. Curing not only helps to take away some of the heat of hydration, but it helps to mitigate the surface from drying out and cracking. Fresh concrete will shrink as it

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cures. As it dries out, it shrinks and may crack. It is proper practice always to protect against cracking in concrete.

Placing temperature

26. At the dam, the temperature that comes out of the batching plant has to be lower because as the concrete is transported by truck or by conveyor, it gains heat. It must be mixed and deposited out of the mixer at a temperature that accommodates whatever heat gain is going to take place from the batch plant to the lift. That is why for RCC dams there are always people with the responsibility for quality control in monitoring the temperature of the concrete at all times from batching, mixing, and placement.

Placing and Compaction

27. If placing by truck or conveyor, and spreading by dozer and compaction by vibratory roller are not done properly, the layers can have 'pockets' of unconsolidated material in spite of the RCC mixture design. Cross-sectional cuts through improperly placed and compacted RCC have shown concrete with pockets of uncompacted RCC. That is not good. The means and methods of delivery and spreading plus size of the roller and the number of passes of a roller are important in minimizing the possibility that such pockets may occur.

28. At the foundation, RCC placement starts with a bedding mix on top of the rock. With a specified layer of bedding mix, the potential for loss of paste from the RCC mix into a depression or opening in the rock is reduced.

29. The dozer driver operates on top of the previous lift and pushes the RCC in front of the dozer onto the receiving layer, the fresh RCC having been deposited on top of the active RCC lift. It is proper practice always to work ahead of yourself. The driver must not back-drag RCC mix with the dozer blade. That is absolutely prohibited. If

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this occurs, it encourages separation of large aggregate particles. They drop off and create segregated material against the shoulder. When RCC is dumped on the active lift and pushed ahead of the dozer, the RCC is deposited in an even thickness layer and when the roller comes along the new RCC layer becomes one with the layer beneath. It is poor practice to dump or pile RCC on old lifts and to move the RCC large distances backward toward the working edge rather than forward from the leading edge of fresh RCC.

30. If you are nearing the abutment or the upstream or downstream form, you want to be pushing the RCC ahead of you toward those boundaries. You never want to see a dozer sitting back near the boundary and pushing away from it as you should be trying to create a very good bond with the forms and a very good bond against the rock foundations.

31. One does not want the roller coming in 30 or more minutes later because the driver was preoccupied, or something was causing a delay or interruption in compaction. The sequence ought to be optimally exercised, with the steps moving in a timely manner and in concert with one another.

Operating sequence

32. The operation should be set up so that the delivery of trucks or conveyors are operating on the working lift, behind which the dozer sits, and behind that, the 10 tonne vibratory roller. When fresh RCC is deposited on the working lift, the dozer spreads it and does several loads down the line. The driver of the compaction machine comes along next and compacts the RCC with a certain number of prescribed passes. The number of passes are predicated on achieving a certain specified density of the RCC. Tests are

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done using a nuclear testing gauge to determine whether the specified densities are being achieved.

33. It is intended that operations on the lifts be carried out in a planned sequence. The idea is to dump RCC, then spread it and compact it within a certain period of time. Inspectors are assigned responsibility to watch for that level of execution.

34. If RCC placement starts at the left abutment and moves across to the other side, RCC placing operation generally turns around and returns back to the other abutment and the next adjacent layer of RCC is place and compacted. When the other side is reached, the next lift is started from the right abutment and work to the left again. It is undesirable to have too much front open at any one time. That is how the leading edge is kept fresh to receive material to be compacted so that this edge is fully incorporated into the new material.

35. If a leading edge is not going to be fully compacted, it may have segregated material within it. When it dries out it forms a potential layer of poorly compacted or segregated material. This should be avoided. Hence, a live leading edge is needed and good practice always calls for working forward from there.

Restoring the surface

36. Once a lift is spread and compacted and it is being water cured, it should never be allowed to dry out. It is cured continuously until the next layer is deposited. If it dries out, the surface must be prepared with high pressure water blasting or the use of a bedding mix. The surface cannot be contaminated and must be kept very clean. Nothing should be spilled on it. There should not be tracks, dust, dirt, mud or any other foreign substance such as fuel or oils that come in from off the site onto the lift. If that occurs, cleaning of the lift is essential before any fresh material is dumped and

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compacted: it must be restored to pristine condition including removal of unacceptable RCC.

Paradise Dam

37. RCC technology started in the 1960s and 1970s. In the 1970s, 80s and 90s, the preponderance of dams were built using low paste mixes. Paradise Dam was built in 2004 and 2005. That is only 15 years ago. It was not in the generation when we were just getting started. The practices set out above in paragraphs 23 to 36 above were well settled by the time Paradise Dam was designed and built. The relevant standard at the time was "*Gravity Dam Design*" by the Corps of Engineers dated 30 June 1995.

38. I have not visited the site of Paradise Dam. I was not there when the Dam was under construction. Sunwater provided the Panel with photographs and site visit observations from its technical consultants, predominantly (as I understand it) from the Burnett Dam Alliance. My comments in section 3.2 of Report No 2 are in part based on those documents, including the following:

    (a) Burnett Dam Alliance, "*RCC Quality Control Report, Report No. 3, September 2.004*" (**September 2004 Report**) attached and marked "**GT3**" **[SUN.110.002.0158]**;

    (b) A series of memoranda provided to the TRP by Sunwater that appear to have been prepared by Mr Jose Lopez or Mr Roberto Montalvo (and sometimes both) during 2004. In particular, I had regard to the memoranda numbered 22, 23, 24, 31, 33, 35, 38, 41, 42, 43, 10.4.5 and 44 **[SUN.009.002.0147]**; and

    (c) A series of memoranda provided to the TRP by Sunwater that appear to have been prepared by Mr Lopez or Mr Montalvo (and sometimes both) during 2005.

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In particular, I had regard to the memoranda numbered 47, 50, 52, 60, 70, 71, 78, 80, 81 and 85 **[SUN.009.002.0203]**.

39. I spent some time looking at and going through the written reports to which I have referred, which contain photographs. From these and the material provided to me by Sunwater, I observed the following:

    (a) the organisation of the equipment;

    (b) personnel and RCC placing operations (which had the potential of contributing to poor lifts);

    (c) placing and dozing RCC *away from* forms; and

    (d) multiple layers having been discontinued at several different locations.

40. These observations were the basis for my remarks in section 3.2 of Report No 2. I wrote those remarks after reviewing those reports that were generated by onsite observers during the ongoing construction. There was evidence, in my opinion, of contamination, segregation, and of the poor practices that were not consistent with the proper practice that I have described above at paragraphs 23 to 36.

Exposed leading edges

41. I saw in the photographs, a partially completed layer with an edge, another layer stepped back a certain distance with an edge, another layer on top of that stepped back a certain distance and an edge. Examples can be seen in A1-11 and A1-28 in Annex A to

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the September 2004 Report [**SUN.110.002.0158**, see pages **SUN.110.002.0228** to **SUN.110.002.0232**].

42. That is not good practice because it creates multiple shoulders which are susceptible to poor compaction and the presence of poorly or unconsolidated pockets of RCC.

Lack of water curing

43. I observed surfaces which had little or no apparent water curing. It can be seen how the colour got darker like things do when they get wet. For example, this can be seen in picture A2-21 in Annex A to the September 2004 Report [**SUN.110.002.0158**, see page **SUN.110.002.0236**]. I extrapolated from that photo and other areas where there was no activity that the RCC would appear to have been placed some time beforehand and it had been left as is with no water curing. Whether or not those surfaces were refreshed before new RCC was placed, I do not know. We have no record of that. Proper practice would require that they received treatment before the next layer of RCC was placed upon them.

Use of bedding mix

44. The design of the Paradise Dam called for use of bedding mix. My colleagues, Mr Peter Foster and Mr John Young in particular, had the opportunity to look at core samples, examine them, and touch them. They, along with the rest of the members of the Panel, wrote in the panel reports that it was difficult to find evidence in the zone where cores had been taken (and where there was supposed to be bedding mix) that there actually existed any bedding mix on the lifts.

45. Other cores were taken horizontally along the lifts and the core simply opened up. It did not break apart: it just opened up. The surfaces were actually dusty, suggesting that

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perhaps some of these surfaces had not been cleaned properly before RCC had been placed. I included a photograph of a sample like that on page 12 of Report No 2. One possible explanation for this observation is that the surfaces were not sufficiently cleaned before the next layer of RCC was placed upon them. That possibility is relevant because of the photographs showing surfaces in poor condition, quality control conditions described in daily inspection notes stating as much, and the referenced samples exhibiting debonding along a lift line.

46. If the hypothesis put forward in the previous paragraph has any legitimacy, it is questionable whether use of the bedding mix would have improved the bond between the RCC layers. The bedding mix is not like a glue: that is not what it is supposed to do. One is not gluing the layers together. The purpose of that technique is to apply an enriched material that has a much higher slump than the RCC. It can be put down on the surface and broomed into the previous layer. When new RCC is applied, a boundary exists between the new and the old that is rich in cementitious material (unlike the RCC). If that surface is not saturated surface-dry or if it has been contaminated with dirt, oil, mud, etc. and is not clean, the bedding mortar simply falls on that unprepared surface. It is debatable whether it would provide the expected or design level of shear strength in that circumstance.

Training of construction personnel

47. In the memoranda by Mr Lopez and Mr Montalvo that I read and to which I referred above, there were comments made about operators of the equipment. It was reported

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that new people were in many cases operating the equipment who had not been trained or who were operating the equipment improperly.

48. One of the required activities that has been standard in all of the RCC dam designs, is that before the actual construction on the dam starts, there must be a test section. The proposed mix design, the techniques for placing, and so on are set out by the design engineer. The contractor is required to place various lifts demonstrating its capability, its tools, and its means and methods for how it is going to achieve the specified quality of RCC. The lifts are evaluated by the construction management team and the engineer on behalf of the owner. The contractor is told to change or improve before being allowed to enter onto the site and start placing RCC. This is proper practice when building RCC dams, both now and in 2003-2005 when Paradise Dam was built.

49. In the early days (i.e. before Paradise Dam was designed and built) the purpose of the test section was to demonstrate the skill levels and expertise of a contractor's proposed team of labourers, foremen and superintendents who would be responsible for placing the RCC.

50. It was also to evaluate the behaviour and performance of the proposed RCC mixes. The dam building community was far enough along by 2003-2005 to know about the RCC material designs. By then it had been designed and tested in the lab. The mix design had already been settled upon.

51. It was accepted practice in 2003-2005 that the test section was more a demonstration that the contractor had the qualified labour, trained quality control personnel, the right techniques, and the qualified foremen and superintendents. It provided some satisfaction that, when the contractor would move to the dam, all aspects of the RCC

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placing operations would be done properly. If, for example a superintendent or foreman were to fall ill, move away or leave the job, whoever replaces those person(s) must be demonstrated to know what they are doing and qualified in RCC construction technology.

52. In some places in the world, it is mandatory to use union labour on most projects. Union workers might only stay for two or three days and then disappear. The contractor goes to the Union and asks for more workers. They show up and now there are two more untrained workers on the site. If there is no foreperson or a superintendent who is willing to train them up to a minimal level of competence, watch them carefully, point out every time they make a mistake or do something improper, suddenly the entire project can be infected with latent defects, produced by people having little or no qualifications for the job.

53. Examples of under or unqualified personnel and poor practices in the field were recorded repeatedly in the memoranda by Mr Lopez and Mr Montalvo and pointed out as problems. Based strictly on the written materials from Burnett Dam Alliance field inspectors and photographs, I noted instances that were not in accordance with good and proper practice at the time.

Responsibility to deliver to the requisite standard

54. The dam owner can hire an engineer that does the design and the construction management, or it can hire an engineer to design the dam and a separate construction manager to come in and manage the contractor. The Corps of Engineers and the Bureau of Reclamation did their own design and construction management. I was fortunate to be in the Bureau of Reclamation and gained experience in construction and design early in my career. I started out in construction and then went into design.

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There was a very close relationship between what we designed and the people in the field who were managing the contractor.

55. Commonly, part of the construction contract requires the contractor to provide the experience, to specify who is going to run the job, who the superintendent and foreperson will be and what their experience is with this material. Then there are the specifications which ought to contemplate and provide for the proper practices and the considerations discussed above.

56. In such contracts, there are always people identified whose responsibility it is to look after the quality management and the quality control. That is usual and proper practice in the field of RCC dam design and construction.

GHD work

57. I am aware that GHD has done extensive forensics on the Dam and that laboratory testing of RCC cores extracted from the Dam has been undertaken. The Panel supported what GHD is recommending to the owner. There is additional information that has been identified and recommended by the Panel to further characterise the existing conditions within the Dam and future loadings to which the Dam may be exposed. The examination completed to date suggests that there could be some latent defects in the Dam's structure.

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GJm

OATHS ACT 1867 (DECLARATION)

I, Glenn Stuart Tarbox, do solemnly and sincerely declare that:

(1) This written statement by me dated March 3, 2020 is true to the best of my knowledge and belief; and

(2) I make this statement knowing that if it were admitted as evidence, I may be liable to prosecution for stating in it anything I know to be false.

And I make this solemn declaration conscientiously believing the same to be true and by virtue of the provisions of the *Oaths Act 1867*.

Glenn S. Tarbox ..... **Signature**

Taken and declared before me at Wells Fargo Bank **this** 3rd **day of** March **2020.**

Taken By Lauren Manohara

Justice of the Peace / Commissioner for Declarations / Lawyer Notary Public

LAUREN MANOHARA
MY COMM. EXP. 09-01-2022
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