[redacted] [redacted]

The Chief Executive
Queenstown Lakes District Council,
Private Bag 50072, Queenstown.

24 September 2009

Dear Sir/Madam,

QUEENSTOWN AQUATIC CENTRE FAST SLIDE

[redacted] has been engaged to review the design and operation of the waterslide known as the fast slide at the Queenstown Aquatic Centre, in response to a significant number of reported injuries resulting from patrons tipping or rolling in the slide.

The following report has been prepared in 2 parts, Part 1 being the discussion of the ride design and the author's own experience of riding the slide during a site visit, and Part 2 being written following receipt and review of material relating to controlled testing of the slide in accordance with recommendations made in Part 1.

Part 1 of the report was issued on 17 July as a draft report, for consideration by stakeholders.

PART 1:-
DISCUSSION ARISING FROM SITE VISIT, SLIDE EXPERIENCE AND EVALUATION OF SLIDE GEOMETRY AND PHYSICS OF THE SLIDING EXPERIENCE, INCLUDING RECOMMENDATIONS FOR CONTROLLED TESTING OF THE SLIDE.

The discussion which follows relates to Hydroslide A, the 57.2m long slide depicted in the [redacted] drawing number 200(B), with average gradient at 1 in 7.6 and a vertical fall of 7.5 metres over its length. While these figures are reported with slight variations in various documents and correspondence, those variations are not significant to the findings of this report as the comments and analysis do not rely on precise values for length or gradient.

These discussions are presented under the following headings :-

1. Impressions from riding the slide
2. Slide Design and performance
3. Physics of the sliding experience
4. Impact of Water Flow Rate
5. Fundamental causes of overturning or tipping
6. Discussion of ride deliverables.
7. Means of rectification

This report is written in the first person to reflect the writer's involvement in the inspection and in the preparation of this report.

1. Impressions from riding the slide

Based on my riding experience on 5 June 2009, the slide is very fast, and quite abrupt in directional changes. Because of the circular cross-section, and the accompanying laws of physics, it was possible to ride the waterslide in the fully reclined position. No loss of contact with the slide surface was experienced, nor was there an indication of tipping in the slide. I would not however ride the slide in anything but the fully reclined position, as I am convinced that overturning would result. Water and friction marking in the slide indicate high angles of banking of both water and riders. Such elevation is in excess of the 'steady state' elevation one would experience, and this is the fundamental reason for overturning or tipping. If for any reason, a patron's body was elevated towards a sitting position, I anticipate that tipping would result. This is based on the simple physics of the forces normal to the slide surface would still pass symmetrically through the centre of body contact with the slide surface, while the gravity forces act in the vertical plane, resulting in a force couple, or overturning moment. The slide is very steep*, and velocities experienced during the ride would certainly exceed the average velocity indicated by elapsed time from start to finish.

(* The slide is considered to be very steep for a non-linear waterslide. Average gradients are usually in the range 1:9 to 1:11, and changes in direction are fewer in number but with larger angles of direction change. The subject slide path undergoes a series of left-right direction changes, through small angles in most instances, and the slide path does not flow in sympathy with the forces acting on a rider. We are familiar with water slides steeper than the subject, but these feature continuous loops, or with dips in straight sections. Most water slides incorporate larger radius bend transitions into loops where small radius bends are subsequently installed for the remainder of the loop).

2. Slide Design and Performance

My initial reaction to the slide design is that the slide path incorporates several consecutive changes of direction of small magnitude and relatively close spacing. With reference to the [redacted] drawing 200(B) the sequence of sliding is as follows. (I have attached a copy of that drawing for ease of reference)

1.a. Commencing observations at slide component (a7), there is a significant length of straight slide (a8) in which any motion lateral to the direction of the slide centerline is dampened, resulting in more or less stable entry into the bend section (a9).

1.b. Given the very short length of section (a9), the rider's slide path is still heavily influenced by the direction of entry to the bend. At the exit from the bend (a9), riders will be displaced to the outside of the curve, effectively elevated in the slide section and located to the left hand side of the slide centerline.

1.c. While traversing the length of the straight section (a10), the rider's path will be directed across to the right hand side of the slide, and elevated relative to the slide centerline.

1.d. My own observation whist riding the slide was that the slide path is offset to the right hand side of the entry to bend section (a11), resulting in a very awkward entry into that bend, and an exit slide path offset to the left hand side of the bend, but at an angle still inclined away from the slide centerline. Conversely, a proper entry into bend (a11) would result in an exit position offset to the left, but with travel in a direction converging with the centerline of the straight section (a12).

1.e. As noted above the exit from (a11) is accompanied by an elevation to the left hand side of the slide, but in a direction not commensurate with a 'steady state' exit from that bend.

1.f. During the journey down the straight section (a12), riders are travelling on a slide path which crosses the start of bend (a12) in a direction from left to right. This results in excessive elevation on the right hand side of the centerline, and a reversal of that direction by the time of entry into the long bend (a13).

1.g. The travel through bend (a13) is therefore characterized by overshooting the steady-state slide path to the right not long after entry into the bend, followed by a series of overshoots left and right of centerline, and also of the steady-state slide path.

1.h. Upon exit from bend (a13), water and wear marks in the slide confirm that both rider and water are displaced significantly off centerline towards the right hand side of the slide.

1.i. Based on the observation that the long curve (a13) provides opportunity for significant damping of the lateral motion relative to the slide path, we conclude that the lateral forces and motion are excessive at the entry to bend (a13), and causative in relation to overturning.

1.j. The following images highlight some of the processes and slide behaviours.

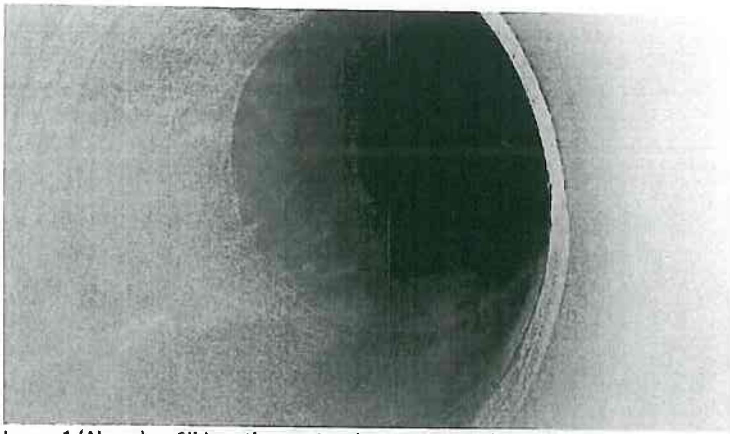


Image 1 (Above). Slide path entering the upcoming left hand bend is on the left hand side of centreline, resulting in overshooting the bend and attaining excessive elevation on the right hand side. On short bends, the rider is placed high on the wall of the slide at the start of the straight section immediately downstream.

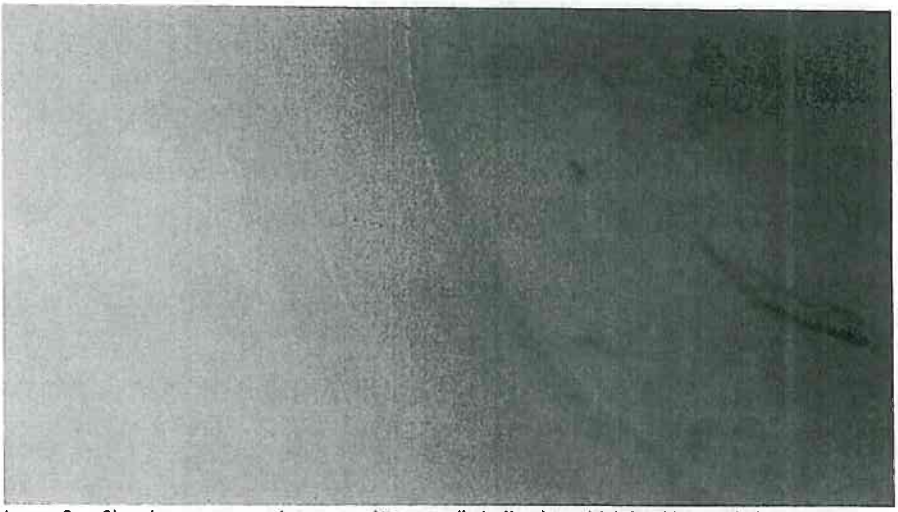


Image 2. Showing scrapes and wear marks generally indicating a high banking angle in this section of curve A13.

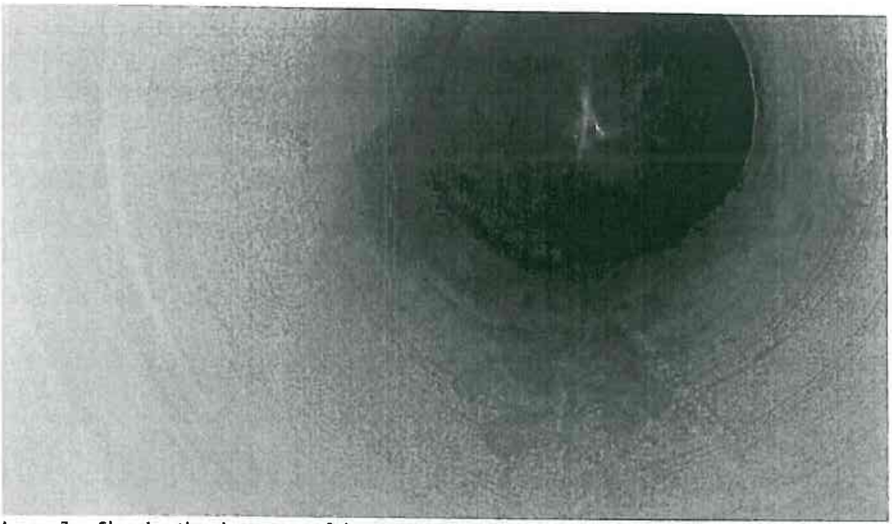


Image 3. Showing the abruptness of the water profile downstream of the exit from bend (a13), and the sharp descent of the water profile in the lower right edge of the photograph. These are the result of the combination of steep slide gradient and short radius bends.

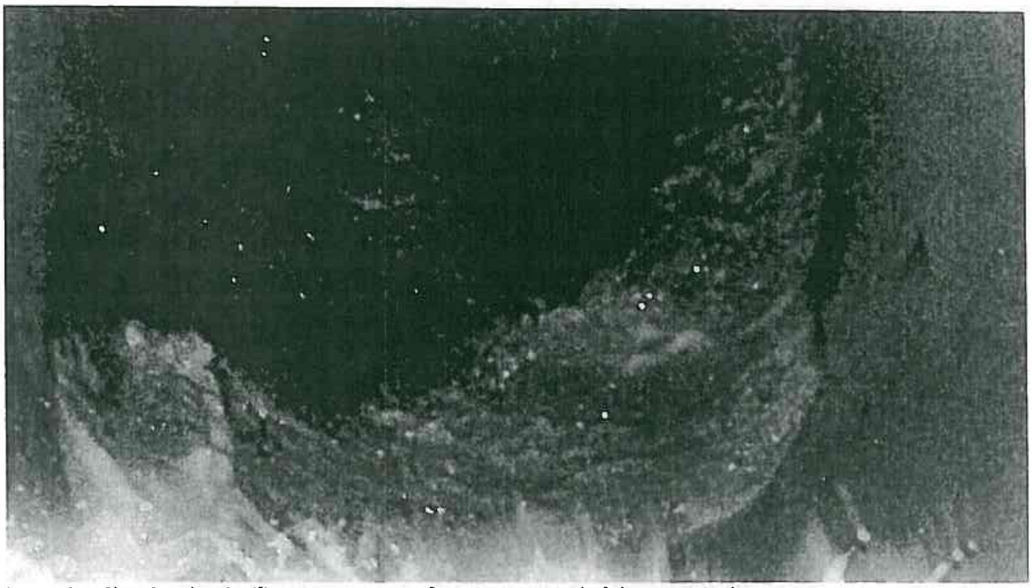
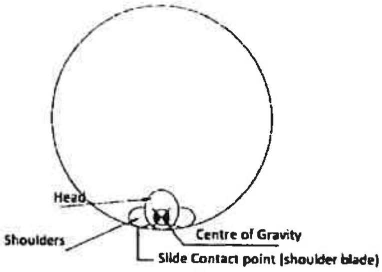


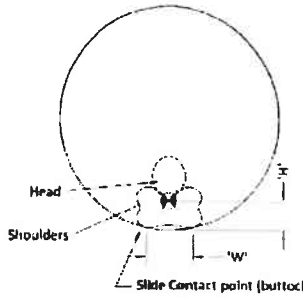
Image 4. Showing the significant component of transverse travel of the water in the slide, in the section between the bend (a15) and the runout. This is again the result of the combination of steep slide gradient and a short radius bend.

3. **Physics of the sliding experience**

The forces acting on a waterslide patron are represented in the two-dimensional sense in the following series of diagrams, which are accompanied by brief explanations.



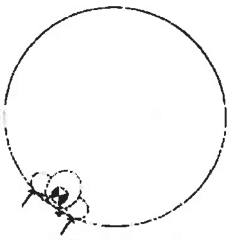
SLIDING IN RECLINED POSITION



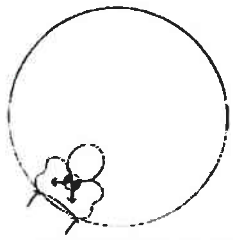
SLIDING IN SEATED OR SEMI-RECLINED POSITION

Diagrams 1 and 2

Note that in the seated or semi-reclined position (at right) the centre of gravity is more elevated than in the reclined position (at left)



SLIDING IN RECLINED POSITION
FORCES ACTING IN A BEND

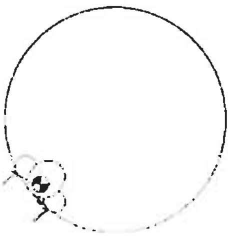


SLIDING IN SEATED OR SEMI RECLINED POSITION
FORCES ACTING IN A BEND

Diagrams 3 and 4

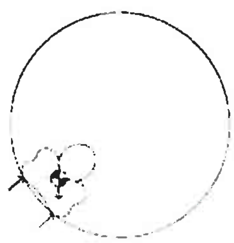
When the rider enters a curve, additional forces are induced, which place the rider offset from the slide vertical centreline, and horizontal forces are introduced. In the reclined position, the line of action of the forces due to gravity and centrifugal acceleration remain more or less central between the forces exerted on the rider by the contact with the surface of the slide.

Note that in the seated or semi-reclined position, those forces are more eccentric to the slide reaction forces.



Queensto

SLIDING IN RECLINED POSITION
FORCES ACTING IMMEDIATELY AFTER A BEND



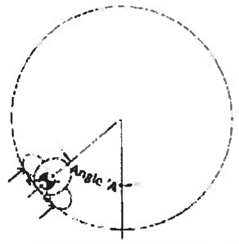
1eei

SLIDING IN SEATED OR SEMI RECLINED POSITION
FORCES ACTING IMMEDIATELY AFTER A BEND

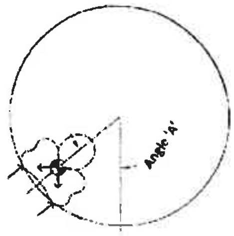
Diagrams 5 and 6

When a rider reaches the exit from a bend, the position in the slide remains unchanged for a short distance, but the centrifugal forces acting in the bend cease to act the moment the rider ceases travelling in the curved path. By the same process, if a rider has been forced into a position too high in a bend section of the slide, relative to the equilibrium height for the instantaneous velocity and ride curvature, the forces acting can also be out of balance.

Depending on elevation within the slide, rider position (seated, semi or fully reclined), the forces can be sufficiently out of balance to cause tipping.



SLIDING IN RECLINED POSITION
FORCES ACTING IN A BEND



SLIDING IN RECLINED POSITION

Diagrams 7 and 8

In the final pair of diagrams (7 and 8), an angle 'A' is labelled to indicate the degree of elevation of the rider within the slide.

A series of calculations has been made to model the sliding behaviour and stability of riders of various sizes and in various postures, for a range of sliding velocities in a bend of centre-line radius 3066mm as found in the subject waterslide.

Note that in the variables included in this analysis, rider mass, velocity, slide diameter and curve radius, mass is not significant to the result.

It is known from experience that many more variable than mass play a part in slide performance, however the calculations serve to clearly indicate the effect and importance on appropriate velocity, slide bend radius and approach geometry to ensure stable positioning of riders within the slide at all stages of a waterslide ride.

Analysis was performed for range of sliding velocities, to determine the equilibrium sliding velocities for an ideal mass (no height) in a bend of two radii, the corresponding overturning velocities for a real mass with height above the sliding surface, and the overturning velocity for the same mass sliding on a straight section of slide, but with elevation in the slide (this latter case is illustrated in Diagrams 7 and 8.)

The results of those calculations are presented in the following tables.

Queenstown Hydroslide

Radius of Bend Section	3.066	m
g (Accel due to gravity)	9.81	m/s/s
Base width of rider	250	mm
Height to Centre of Gravity	100	mm

Steady State Sliding in a Bend Velocity m/s	 Angle 'A' Degrees	Overtipping Angle at same Velocity (Deg)	Overtipping Angle on straight slide (For all velocities) (Deg)
3.60	23.3	59	52.0
3.80	25.6	59	
4.00	28.0	60	
4.20	30.4	61	
4.40	32.8	61	
4.60	35.1	62	
4.80	37.5	63	
5.00	39.7	63	
5.20	42.0	64	
5.40	44.1	65	
5.60	46.2	66	
5.80	48.2	66	
6.00	50.1	67	

Queenstown Hydroslide

Radius of Bend Section	3.066	m
g (Accel due to gravity)	9.81	m/s/s
Base width of rider	250	mm
Height to Centre of Gravity	200	mm

Steady State Sliding in a Bend Velocity m/s	 Angle 'A' Degrees	Overtipping Angle at same Velocity (Deg)	Overtipping Angle on straight slide (For all velocities) (Deg)
3.60	23.3	45.0	33.0
3.80	25.6	47.0	
4.00	28.0	48.0	
4.20	30.4	49.0	
4.40	32.8	50.0	
4.60	35.1	51.0	
4.80	37.5	52.0	
5.00	39.7	54.0	
5.20	42.0	55.0	
5.40	44.1	56.0	
5.60	46.2	57.0	
5.80	48.2	58.0	
6.00	50.1	59.0	

The above tables relate to the existing slide bend radii of 3.066 m centreline radius utilized throughout the slide's construction. Attention is drawn to the rapid loss of stability brought into play should a rider sit up on the slide. The height of 200mm would still be significantly below the potential height to the centre of gravity of a rider in the erect seating position. Also of particular significance is the large reduction in the stable angle of the semi-reclining rider upon entering a straight section (from 52 degrees for the reclining position down to 33 degrees). The tipping angle of 33 degrees is smaller than the stable velocity for all velocities greater than 4.4 metres per second.

In the following tables, the slide centreline radius has been increased to 4.5m, to illustrate the gains in stability made from utilizing larger radius sections as entrances to bend sections, and while the practice of making small, closely spaced angular changes of direction in water slides is not endorsed, the increase in bend radius does soften the impact of the bends.

The slight decrease in overtipping angle in the larger radius bend is due to the adjustment made in the analysis to reflect the increase in distance (radius) from the centre point of the slide bend as the rider mounts the slide wall.

Queenstown Hydroslide

Radius of Bend Section	4.5	m
g (Accel due to gravity)	9.81	m/s/s
Base width of rider	250	mm
Height to Centre of Gravity	100	mm

Steady State Sliding in a Bend		Overtipping Angle at same Velocity	Overtipping Angle on straight slide (For all velocities)
Velocity m/s	Angle 'A' Degrees	(Deg)	(Deg)
3.60	16.4	57	52.0
3.80	18.1	58	
4.00	19.9	58	
4.20	21.8	59	
4.40	23.7	59	
4.60	25.6	60	
4.80	27.6	60	
5.00	29.5	61	
5.20	31.5	61	
5.40	33.4	62	
5.60	35.4	62	
5.80	37.3	63	
6.00	39.2	64	

Queenstown Hydroslide

Radius of Bend Section	4.5	m
g (Accel due to gravity)	9.81	m/s/s
Base width of rider	250	mm
Height to Centre of Gravity	200	mm

Steady State Sliding in a Bend Velocity m/s	 Angle 'A' Degrees	Overtipping Angle at same Velocity (Deg)	Overtipping Angle on straight slide (For all velocities) (Deg)
3.60	16.4	42.0	33.0
3.80	18.1	43.0	
4.00	19.9	44.0	
4.20	21.8	45.0	
4.40	23.7	46.0	
4.60	25.6	47.0	
4.80	27.6	48.0	
5.00	29.5	49.0	
5.20	31.5	50.0	
5.40	33.4	51.0	
5.60	35.4	52.0	
5.80	37.3	53.0	
6.00	39.2	54.0	

4. Impact of Water Flow Rate

One of the controllable variables affecting sliding velocity in a waterslide is water flow rate. In moderately-sloped waterslides, increasing water flow rate tends to reduce sliding velocity, as water is accumulated ahead of the rider. Hence, increasing flow rate can reduce the sliding velocity.

Water flow velocity has been calculated for the following conditions, to establish an indication of sliding velocity.

Slide Diameter	1366mm
Slide Slope	Refer Table
Material of Slide	GRP, polished
Estimated Manning's 'n'	0.010

Table 1.
Calculated Water Flow Velocities, Steep Slide
Slope 1 vertical in 7.6 horizontal

Flow Rate (lps)	Calculated Flow Velocity (m/s)
55	3.6

65	3.8
85	4.1

Table 2.
Calculated Water Flow Velocities, Moderately-sloped Slide
Slope 1 vertical in 11 horizontal

Flow Rate (lps)	Calculated Flow Velocity (m/s)
55	3.1
65	3.4
85	3.6

It is common for a moderately sloped waterslide to operate with a flow rate in the vicinity of 85-90 litres per second, for which the calculations suggest a water flow velocity of approximately 3.6 metres per second, while velocity at flow rate 55 lps is 3.1 metres per second.

At this same flow rate, the subject slide is seen to have a calculated water velocity of 4.1 metres per second, while velocity at flow rate 55 lps is 3.6 metres per second.

Examination of the photograph (Image 4) of flow patterns at the slide exit indicates that the flow path is considerably longer than slide invert, and an increase of path length of 8-10% could be involved. Coupled with the influence of turbulence, and an effective reduction in slide slope (10% due to the extra length) effective velocity of the flow could be as indicated in Table 3 below.

Table 3.
Calculated Water Flow Velocities, Steep Slide with turbulent, lengthened flow path.
Slope 1 vertical in 8.3 (7.6+10%) horizontal

Flow Rate (lps)	Calculated Flow Velocity (m/s)
55	3.4
65	3.6
85	4.0

An observation is made at this point that the respective flow rates in Table 3 represent the following mass per metre of water in the slide.

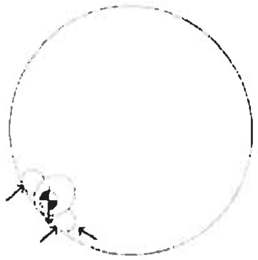
Table 4.
Calculated Weight of Water per metre of slide, based on flow rates presented in Table 3.

Flow Rate (lps)	Calculated Flow Velocity (m/s)
55	16
65	318
85	21

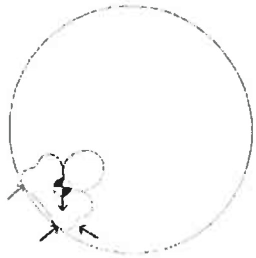
If the slide path is different from the water flow path, then at some points the two trajectories will cross.

While the linear velocities of the rider and water will not be significantly different, there is potential for their directions to be quite different, given the observed severity of meandering of water downstream of the last bend in the waterslide (Image 4).

An additional force is introduced into the analysis, as indicated in the following diagrams 9 and 10. This force is the result of the rider's path crossing that of the water.



SLIDING IN RECLINED POSITION
FORCES ACTING IMMEDIATELTY AFTER A BEND
WITH SLIDING DIRECTION OPPOSED TO WATER FLOW



SLIDING IN SEATED OR SEMI-RECLINED POSITION
FORCES ACTING IMMEDIATELTY AFTER A BEND
WITH SLIDING DIRECTION OPPOSED TO WATER FLOW

Diagrams 9 and 10

This force, by examination, increases the overturning tendencies inherent in the fundamental forces involved in the physics of sliding.

One further observation is that unlike the forces involved in sliding which are all related to the rider's mass, this interaction with the water is between the rider's mass and that of the water. Hence the force is likely to have more impact on smaller riders.

5. **Fundamental causes of overturning or tipping**

The following factors are of further significance in the matter of tipping/overturning in waterslides :-

The human body is not a rigid element, and in a seating position the legs and hip regions may not contribute fully to the stability which might be associated with the mass of an equivalent solid. In the fully reclined position the forces act similarly over the length of the body. In the seating position the lateral forces are exaggerated over the upper parts of the body.

Additionally, as outlined in section 4 above, there is an additional force which can act on the rider (Diagrams 9 and 10), and which will act on that part of the rider located against the slide surface.

In the fully reclined position, the force will act more or less over the length of the rider.

In the semi-reclined or seating position, the force will act on the lower part of the body only, and in a location ahead of the upper body mass.

The first aspect of this force to be taken into account is that it is introduced suddenly as the rider encounters the water mass.

Secondly, this force acts on the part of the rider which first encounters the water, that is the legs.

In the reclined position, a rotation and a deceleration will be induced.

In the semi-reclined or seating position, the force will additionally induce overturning due to the vertical separation of the force and the rider's elevated centre of mass.

The slide presents some variability in friction, slope and longitudinal profile encountered in the slide path which is not modelled in the analyses presented. These factors (such as braking on the elevated sections of bends, and the tendency for the slide surface to drop away in front of the rider) act to further destabilise a rider.

When the following variables are encountered in preparation of a slide model, it becomes clear that water slide design is more concerned with performance envelopes rather than being an exact science.

- Patron weight
- Patron build
- Patron Body Mass Index
- Patron posture on the slide.
- Patron speed at the entrance to and exit from a bend
- Depth and flow rate of water in the slide
- Condition of the slide surface
- Slide slope
- Condition and material of the rider's attire (Consider slick synthetic materials compared to cotton shorts and T-shirt).

In preparation of the above analysis, we have not attempted to assume a design velocity for the rider, but rather a range of velocities which permit the evaluation of some predicted performance data.

Site measurement of slide velocity can also be misleading due to the time required to accelerate at the beginning of the ride, variability in slope over the length of the slide, the length of the rider's slide path, which due to meandering is longer than the slide centre-line length, and interaction with the water in the slide.

6. Discussion of ride design and deliverables

The design brief would require a balance between thrill and safety.

In essence, there is little thrill element in a waterslide unless it is accompanied by a perception of risk and challenge. The designer's task is to incorporate that thrill element into a slide environment that is inherently safe. This inherent safety may not be immediately understood by the rider, adding to the thrill. On the other hand, a sense of safety not borne out in the fundamental design of the water slide is not an indicator of good design.

The extent to which the slide has to be immune from injury incidents arising from the effects of elevation of the rider's centre of gravity (that is, approaching a seating position rather than a reclining position) is a function of design briefing, product description and facility operator's expectation.

One would expect that if a slide's performance was such that any departure from a fully reclined position would result in a sharply increased risk of injury, then that would be a highlighted aspect of the design submission and description.

The foregoing analyses, whilst brief and to a degree simplistic, indicate that the ride's inherent safety is highly reliant on the posture of the rider.

The degree to which this was communicated, desired and understood between the parties is outside the scope of this report.

7. Means of rectification

Preliminary suggestions for rectification of the issues are :-

(a) Lessen the slide gradient (obviously quite impractical at this stage)
(b) Lessen the severity of the changes of direction, primarily by replacement of the 3075mm radius curves (a9) and (a11) with segments of the same degree of bend but of larger radius.
(c) Soften the entry into the curve A12 by insertion of a lead-in section of larger radius.
(d) Perform further testing of ride performance at varied water flow rates.

Item (d) can of course be performed without alteration to the slide, but may not produce across-the-board protection against overturning.

Some guidance can be taken from the history of injury incident occurrence and flow rate in operation, though this appears to have has been blurred to some extent by an un-documented adjustment to the flow rate setting.

The latter points 2) and 3) could both be carried out with significantly less disruption to the installation than is entailed in point 1).

It is our opinion that it is not reasonable to expect patrons to recline for the whole slide journey, given the abrupt nature of the direction changes, and the awkward positioning of riders induced by the geometry of the slide.

Reflex actions surely suggest otherwise when faced with uncertainty of upcoming slide direction, the presence of copious quantities of water and splash, and the experience already had in the upper sections of the ride regarding the unsettling nature of the abrupt changes of direction. The immediate urgency of the ride would over-ride any recollection of the signage or other direction received to remain lying down during the ride.

Additional lighting of the ride interior would not change the performance of the ride, and may in fact encourage riders to elevate themselves to better gauge the upcoming direction of the slide. The ability to gauge the ride path and to cope with the forces involved may not be inherent in each individual, and it is not reasonable to expect riders to make appropriate adjustments to posture and 'bracing' at the speed at which the ride develops in front of them.

Consideration should be given to requesting from the slide designer a response to the contents of this report. It should be within the capability of the slide designer to also make suggestions for an improvement in the safety of the ride, and a broadening of the envelope of safe riding posture. The safety of a riding posture is a function of the rider's lateral positioning in the slide under changes of direction, which is in turn a function of the slide's geometric design.

We consider the geometric design of the slide to be lacking in this regard.

To progress the re-introduction of this ride to service we recommend the following methodology.

1. Water Flow Rate Adjustment and Trialling.
    a. Hire or purchase and install an accurate flow meter on the slide delivery pipework, so that flow rate can be recorded in litres per second, rather than at 3rd, 4th etc notch on the butterfly index plate.
    b. Trial the slide with a range of rider's with prior experience of riding the slide, and always sliding in the reclined position. The range of riders participating in the trial should be representative of a cross-section of patrons normally using the slide, and be of varied body size, weight and build and generally of the target market age group.
    c. Record ride times from the last viewing port to the exit of the last bend.
    d. Have riders observe their progress relative to the water flow path, and record comments concerning where the slide path may have intersected the flow path.
    e. Record these observations for a range of at least five riders, and with flow rates ranging between 20 and 60 litres per second, at 5 litre per second increments.
    f. Record the maximum flow rate available from the system (for calibration purposes with reference to our previously advised system flow rate).
    g. When conclusions can be drawn regarding the impact of riders intersection with the water flow path, and the impact of flow rate and ride experience, further testing might then be undertaken by those same riders, in semi-reclined and sitting postures. It would be advisable to wear some measure of head protection during this stage of testing.
    h. Following compilation of this test data and review, a decision would be made regarding re-commissioning of the ride.

If the trials produce definite outcomes in terms of defining a safe operating regime, then the slide could be re-commissioned. This would be accompanied by steps to secure the desired flow rate from the slide supply pump, which may include reduction in impeller diameter, and fitting of an orifice plate or regulating valve which would be locked in position at the desired flow rate.

Failing achievement of this outcome, consideration would need to be given to amendment of the ride geometry.

PART 2:-

ASSESSMENT OF RESULTS OF CONTROLLED TESTING OF THE SLIDE AND REVIEW OF VIDEO FOOTAGE OF THE SLIDE TAKEN BY A RIDER IN THE CONTROL GROUP

(Note that the video recording was made using a hand-held camera carried by an experienced dive instructor. The dive instructor had attempted riding without the camera and in a sitting position, and had tipped in the ride and incurred minor injury. No recording was carried out in the sitting position due to the perceived risk of injury in so doing)

In summation of the correspondence and reports received as a result of the controlled testing carried out on the slide, the following can be stated.

1. Riders did not experience tipping when riding in the fully reclined position.
2. There was a tendency for a rider to rise from the reclined position to gain a better view of the slide ahead, and to rise above the impact with the water in the slide.
3. Most riders were not confident to ride in a position other than fully reclined.
4. The geometry of the slide presented a slide path incongruous with the physical path followed by the riders.
5. Water flow rate played a significant role in determining ride speed and behaviour.
6. Conclusions

These items are discussed in further detail.

1. **Fully reclined position.** This is the stated position for riding the slide, however the timing of the issue of this instruction between supplier and operator is not discussed in the context of this report. Taken from the opposite viewpoint, riding in anything other than a fully reclined position will most likely result in tipping. This was not established by trial, due to the perceived likelihood alone of the occurrence of tipping when not fully reclined, and the obvious preference to not instruct behaviour which would possibly result in injury.

2. **Tendency to rise.** This is expected to be a strong reflex action for most riders, and when not countered by an understanding of the likely consequences of such action, would result in tipping.

3. **Riding not fully reclined.** The experience of riding the slide in the prescribed reclined position reinforces the instability imposed by the slide geometry and the incorrect placement of a rider within the slide section in several parts of the ride length. The thought arises that riders who have suffered tipping in the past might have been first timers, not prepared for the ride experience. It is also not reasonable to expect riders to possess sufficient skills to evaluate the safest way to negotiate the slide. The safety is required to be inherent in the slide design.

4. **The physical slide path is incongruous with the rider's path.** This observation was made in Part 1 of the report, and the photograph and caption at Image 1 were presented to illustrate this point. The following image is taken as a still

capture from the controlled ride video footage, and illustrates the degree to which both water and rider are displaced on the wrong side of that curve at entry. From observation of the full video record, it is obvious that this incongruous entry to the subject bend amplifies the instability in the ride, and subsequent and somewhat violent oscillations in the rider's positioning in the slide can be seen. There is an abrupt change in the rider's direction of travel observed approximately four (4) seconds after passing through the bend labelled (a7), and this is seen to have a destabilizing effect on the rider's position. It is not clear due to the darkness of the ride whether this is due to the bend labelled (a9) or (a11). As a further observation, the final, long left hand bend in the slide presents a more controlled section of ride, however the degree of oscillation is difficult to judge from the video. Observation of the water splash encountered suggests there is a degree of oscillation, however it is well dampened upon entering the light at the ride exit.

It is obvious that the geometry of the ride in the interval bounded by bends (a7) and (a11) is the causative factor in the injury outcomes recorded to date.

This conclusion is reinforced by observation of the impact on the rider as seen in the video recording.

the slide video taken during controlled testing, which confirms the observations made in Part 1 regarding slide geometry and placement of the rider in the slide..

5. **Water flow rate.** Testing determined that the most stable ride conditions were encountered with the flow rate set to Notch 3. The various flows achieved at respective butterfly valve index plate 'notch' settings were reported from site testing with a magnetic flow meter in accordance with the values in the following table. For future control over flow rate control, installation of a mechanical device such as an orifice plate, or impeller machining should be performed to match the desired flow rate of 67 litres per second and to remove

the risk of inadvertent re-setting of the flow rate.

Notch	Flow rate L/s
2	45
3	67
4	83
5	95
6	99
7	101
8	103
Fully open	107

6. **Conclusions From The Controlled Testing Of The Slide.** The slide is not inherently safe, and must be ridden in a fully reclined position.

REPORT CONCLUSION

The practical implications of the requirement for the ride to be ridden in the fully reclined position are outside the scope of this report, but they include the need for a high level of ride supervision and rider awareness at the commencement of each slide by each rider. Further, there is no means of enforcing the reclined position once the rider has departed from the start point of the slide. No assurance can therefore be provided that riders will maintain a fully reclined position, nor is there any means of confirming that a rider has or has not maintained a reclined position during the ride.

The consequences of these uncertainties in the case of injury must therefore be assessed by the slide operator before going ahead with the operating regime suggested by the slide designer.

There is no comprehensive assurance in the controlled testing that some riders will not be tipped in the slide, even if adhering to the fully reclined position, such is the impact on the rider of the sudden changes of direction experienced in the slide.

It is the author's opinion that the ride should not be operated without alteration in the portion of the slide located between (and necessarily including) bends (a7) and (a11), sufficient to ensure that the slide path induced by the geometry of the slide is consistent with the geometry of the slide. This geometric requirement is clearly not inherent in the current slide configuration.

Yours faithfully,

[redacted]