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# Abstract

In spite of the undoubted aesthetic importance of water clarity, apparently no studies of human detectability of clarity changes have been made. In this study, finely divided limestone (calcite) was injected into a small natural stream (flow = $349\ \mathrm{l\ s^{-1}}$) and the resulting changes in water appearance were monitored by panels of observers while the in-stream concentrations were monitored instrumentally. Initially the stream bed (gravel with some sand) was clearly visible at depths of 760 mm or less through water of 1.5 m visual clarity (horizontal sighting range of a black disk). The cue to increased turbidity is probably partial obscuration or "fogging out" of bed features. Median detection thresholds (just noticeable differences) in terms of reduction in visual clarity below background (initially with the bed clearly visible) were 12 and 10 % for two independent panels (each with $n = 11$) who observed the visual changes as turbidity was increased monotonically. This low detection threshold represents a remarkably high human sensitivity to turbidity change that may be generally applicable to small, clear streams.

## Introduction

There are numerous references in the literature to the importance of aesthetic quality and recreational values of water bodies, as affected by change in water colour and clarity. However we are aware of very few studies to determine human detectability of such changes in waters. This is somewhat surprising because most western countries including New Zealand have standards or guidelines to protect the visual and aesthetic quality of waters. Apparently these numerical criteria are based not on objective bioassays with the "human organism" but on untested expert opinion.

The New Zealand legislation for the conservation of water (i.e. the present Water and Soil Conservation Act 1967 and reforming legislation in preparation) prohibits a "conspicuous" change in natural colour and clarity of waters. At present it is not known what level of change in aspects of color and clarity (see Glossary) of water are conspicuous. Indeed only recently has it become apparent what measures are appropriate for defining colour and clarity (e.g. Kirk 1988).

We may observe that a conspicuous level of change must necessarily be greater than a detection threshold. How much greater "conspicuous" is than merely "detectable" is largely a value judgement and might have to be investigated by the methods of hedonic testing (i.e. by surveying what people actually *feel* about a change rather than merely what they can detect), if indeed it were amenable to scientific study at all. This is beyond the scope of the present study which focuses only on detection thresholds which are necessarily a lower bound to conspicuous levels of change.

The detectable level of change in any measurable aspect of colour and clarity might be expected to depend on a number of factors including the viewing configuration and type of water body. However, Weber's law of psychophysics, which states that the magnitude of a stimulus is proportional to the *relative* change, gives us some reason for expecting that detection thresholds for measures of colour and clarity expressed in terms of relative change may be fairly similar in quite different situations, so long as the *mechanism* of perception remains unchanged. Thus some experiments on detectability of colour and clarity change in “realistic” and “typical” conditions may yield useful generalisations.

Only one on-site study of human perception of water quality appears to have been carried out previously in New Zealand. Wilcock and Davies-Colley (1986) reported a field panel study of the detectability in the Tarawera River of highly coloured Kraft effluent from the Tasman pulp and paper mill. This study, modelled in part after the very comprehensive study of Whittemore and McKeown (1978) in the United States, involved manipulation of the loading of the Kraft effluent so as to define a just noticeable difference (JND) in colour of the river water over background colour. The findings of this study, and those of others cited by Wilcock and Davies-Colley, suggest that human observers are acutely sensitive to changes in water appearance over relatively short time periods (hours).

The panel study reported here was broadly similar in concept to that of Wilcock and Davies-Colley (1986). The purpose was to measure the threshold of detection of colour and clarity changes induced by inorganic suspensoids discharged to a natural stream. Such discharges of light scattering (rather than absorbing) material are a fairly common practical problem for water managers concerned with, for example, mining discharges and runoff from construction sites. We chose to use an intensely light scattering but non-absorbing material: finely ground limestone (calcite) to produce "artificial" turbidity in the stream water. Panels of observers viewed the stream water at different sites and recorded when they observed a change in stream appearance over background. From this data detection thresholds could be determined. Additional details on the design (including the questionnaires) and results can be found elsewhere (Davies- Colley and Smith, 1990).

## Methods

### Experimental design

Figure 1 illustrates the broad concept of the experimental design. A slurry of inorganic suspensoids at high concentration was discharged to the stream at an increasing rate of flow so as to increase stream turbidity monotonically. The resulting stream concentrations were monitored with a continuously recording sensor (transmissometer) and discrete sampling. Meanwhile, panels of observers were asked to record times at which they noticed a change in stream appearance.

The main question to be addressed was: what increase in stream turbidity over background is detectable? We were also concerned with verifying that people can see a change in water turbidity before the increase has been sufficient to completely obscure the bed and that depth of water is not particularly important so long as bed features are initially visible. It was also of interest to examine memory of the initial appearance of the stream water with a question asking when the water had returned to the background level. (In principle, of course, this takes an infinitely long time).

## Experimental site

A gravel- cobble bed typical of many New Zealand rivers and streams was sought as an experimental site because it was anticipated that the appearance of the bed viewed through the water would be a major cue to change in clarity. It was also important to select a site where temporary discharge of inorganic suspensoids would not damage stream life or cause undue offence to casual observers of the stream waters. The Waikato Catchment Board was consulted on these matters and some of their staff were involved in the study.

A site on the Waingaro Stream west of Ngaruawahia was chosen. Access was from the Waingaro Road about 3 to 4 km from Waingaro Springs (map reference: N55 523 612). At the time of the experiment the stream was flowing at 349 l $s^{-1}$ in "moderate" baseflow condition with a background turbidity of 3.8 NTU, black disk clarity of about 1.5 m and a beam attenuation coefficient (see Glossary) of 3.106 $m^{-1}$. The experiment was carried out on 25 March, 1988, a fine day but with considerable cloud.

The injection hardware was assembled at the upstream end of the experimental reach (Figure 2) out of sight of the panels. The natural stream channel was divided roughly into two from the injection point to the Panel 1 observation site (about 23 m and 58 s streamwater travel time) using hardboard sheets fixed to steel stakes. The slurry diffuser discharged only on one side of the divided channel. This permitted the Panel 1 observers to directly compare the modified stream water on one side of the divider to the background stream water on the other side, both areas having comparable stream depths of about 200 - 240 mm (Figure 2).

The other two panel observation sites were established some 34 m and 44 m further downstream (the 10 m separation corresponds to approximately 30 seconds travel time, Figure 2). Trial injections on the day before the panel study demonstrated that mixing across the whole width of the channel was complete by the time the water reached the Panel 2 site, largely due to the presence of a riffle between the Panel 1 and Panel 2 sites. All three panels were assigned defined areas of stream surface/bed to observe. These were approximately 1$m^2$ quadrats delimited by coloured tape. Panel 2 observed an area where the stream bed was 350 - 370 mm depth and Panel 3 an area of 700 - 760 mm depth. Clocks placed at each panel site permitted all measurements and observations to be referred to a common time base.

At all three panel observation sites a technician was stationed during the experiment to sample water in the quadrat every 2 minutes for laboratory turbidity measurements (Hach 2100A nephelometer). Between each water sampling the technicians took readings of visual water clarity using a black disk (Davies-Colley 1988). A Martek XMS transmissometer of 0.25 m path was deployed in the stream adjacent to the Panel 3 quadrat. The transmittance ($T$) recorded by a chart recorder on the bridge was later used to calculate the beam attenuation coefficient:

$$c = \ln (1/T)/0.25.$$

## Production of colour and clarity changes in the stream water

The material used to produce the changed water colour and clarity was a commercial limestone (calcite) supplied ground to < 10 μm diameter (median diameter about 3 μm). The slow settling velocity of the particles dispersed in water was consistent with the fine grain size. Preliminary tests showed this material to be non-absorbing of light but intensely scattering with an attenuation crossection of about 0.5 $m^2 g^{-1}$ (i.e. 1 g $m^{-3}$ produces an attenuation coefficient of 0.5 $m^{-1}$). This material greatly changed visual clarity (i.e. sighting range) in water in which it was suspended and also changed the brightness of the water due to increased backscattering. Since a change in spectral light absorption is required to change hue ("colour") of water, this material, being non-absorbing, did not affect hue. The visual impression of this material at high concentrations in the stream water was similar to milk.

The powder was injected into the streamwater as a concentrated slurry of about 40 g $l^{-1}$ (i.e. 40,000 g $m^{-3}$). Low foam laboratory detergent (Anipol) was used as a wetting agent to aid dispersion of the calcite particles in the slurry. No foaming was observed in the stream and we are confident that the only stimulus during the panel experiment was the colour and clarity change produced by suspended calcite particles.

The slurry was delivered using agricultural spray equipment consisting of a truck-mounted tank, high pressure pump and hose terminating in a spray wand. The operator used the valve at the spray wand to top up a travelling bucket suspended from a block and tackle system. The bucket acted as a header tank with variable head with respect to the stream water. The slurry was delivered to the stream by flexible hosing terminating in a four port diffuser designed to maximize mixing in the stream water. The flow rate from the travelling bucket was adjusted every minute by changing the height of the bucket above the stream, so as to monotonically increase stream turbidity.

### Questionnaire design

Panels of observers were formed from a combined chemistry/biology class of 6th formers from Fairfield College in Hamilton. Several days before the experiment was conducted the panelists were told of the broad objectives of the experiment and were shown a litre cylinder filled with the slurry. On the day of the experiment the panelists were taken by bus to the experimental site under supervision of their teachers and assigned to three separate panels.

The information required from the panels was as follows:

| | |
|---|---|
| Panel 1 | 1. The time at which panel members first detected a difference in clarity of the stream water between the two matched quadrats.<br>2. The time at which the stream bottom disappeared in the quadrat on the altered side of the stream. |
| Panels 2 & 3 | 1. The time at which a change in water appearance with respect to their memory of the initial appearance was noticed.<br>2. The time at which the stream bottom disappeared. |

## Results

### Monitoring records

The chart record of transmittance measured by the beam transmissometer adjacent to the Panel 3 observation site was smoothed by simply fitting a curve by eye through the record and scaling off values every minute. Figure 3 shows a plot against time of the beam attenuation coefficient calculated from the smoothed transmittance record. The numbers on the abscissa are minutes after 10.20 am.

The initial ramp was steeper than intended with the result that Panel 1 all saw a change almost immediately. Settling of some of the slurry in the travelling bucket and diffuser system prior to start-up was apparently responsible. The sharp front of initial injection had dispersed somewhat by the time it reached Panels 2 and 3 so that a useable response was obtained for the purpose of calculating just noticeable differences (JND's). The beam attenuation coefficients calculated (as 4.8/y where y is black disk range, Davies-Colley 1988) from clarity observations taken by technicians at the panel sites were in good agreement with those plotted in Figure 3. Turbidities measured on water samples taken by the technicians were in fair agreement with the beam attenuation data.

## Analysis of panel responses

### Panel 1

Panel 1 responses were not analysed in detail because the up-ramp was too steep for a quantitative estimate of JND. However the responses confirm that people are highly sensitive to changes in water colour and clarity - more so than had been anticipated at the time of design of the experiment.

### Panel 2

Figure 4 shows the cumulative percentages of the panel reporting a change plotted against $c$. The response curve is fairly steep (but remember that the panel size was small - only 11 members). The median (50 percentile) is about 3.54 $m^{-1}$. Thus the median JND corresponding to an increase in attenuation coefficient from 3.106 (background level) is a 14 % relative increase. This change in light attenuation corresponds to a 12 % reduction in clarity (clarity being inversely related to $c$ ).

The cumulative percentage of the panel reporting disappearance of the bed is plotted against $c$ in Figure 5. The median is 10.41 $m^{-1}$, corresponding to a black disk range of 0.46 m. This figure for the visual range compares with a streambed depth of about 0.36 m underneath the quadrat.

### Panel 3

The cumulative percentage of panelists observing a change is plotted against $c$ in Figure 6. The response curve is steeper overall than for Panel 2 and does not conform to the typical S-shape, possibly a result of small panel size. The median $c$ value was 3.443, an increase above background (3.106) of 11 %. This corresponds to a 10 % drop in visual clarity.

Observations of bottom disappearance are plotted in Figure 7. The median c value is estimated to be 4.69 $m^{-1}$ . This corresponds to a black disk range of about 1.02 m which compares with a water depth below the observed quadrat of about 0.73 m.

Also shown in Figure 7 for comparison with the disappearance data are the *re*-appearance observations for reduction in turbidity near the end of the experiment. The median reappearance value is 4.81 $m^{-1}$ (corresponding to a black disk range of 1.0 m), encouragingly close to the disappearance value of 4.69 $m^{-1}$.

## Discussion

### Just noticeable change in appearance

The median relative increases in light attenuation coefficient which were just noticeable were comparable for panels 2 and 3 at 14 % and 11 % respectively. The corresponding just noticeable decreases in clarity were 12 and 10 %. This represents a remarkable sensitivity of the human eye to quite small relative changes. Because the values for the two panels viewing very different stream depths (averaging 360 and 730 mm) were very similar it appears that stream depth has a minor, if any, influence on the JND's, although the panel sizes are too small to be very conclusive.

Most response curves relating proportional response to some observable variable are similar to cumulative normal distribution curves (S-shaped). Our response curves do not resemble normal curves, presumably because of the small panel sizes in which a single observer represents 9 %. It is therefore of dubious validity to attempt to estimate parameters of the response distributions other than medians, such as extremes and dispersion measures.

### Threshold visibility of the streambed

There appears to be a relationship between clarity at the point of disappearance/reappearance of the bed and depth of water (Table 1) which we can express very approximately as follows:

$$y_{BD} \cong 1.35\, z$$

where $y_{BD}$ is the black disk range and z is the streambed depth. This relationship indicates that the water depth is smaller than the corresponding horizontal disappearance range of the black disk (by about 26 % on average). This result is not too surprising since the contrast of similarly reflective streambed sediment particles might be generally lower than that of a black disk seen against the water background. Further, the sediment bed is viewed vertically so that attenuation of illuminating light (illuminance) with depth reduces the visual range wheras the black disk observation is horizontal such that visual range is not affected by attenuation of illuminance with depth in the water.

## General

The results of this study demonstrate that human observers are very sensitive to colour/clarity changes in stream waters. The JND's for clarity reduction of the order of 10 % are surprisingly low. This suggests that the water classification standards prohibiting "conspicuous change" in natural colour and clarity of water should be interpreted as quite a small relative change in turbidity, at least where applied to discharge of inorganic suspensoids to shallow and clear streamwaters. Now that the approximate level of detectability of clarity change has been defined, further work is desirable to refine the measurements and examine sensitivity to variables which might be expected to affect perception.

The experiment has given some insight into the attribute of colour and clarity that alerts people to a change in turbidity. Apparently, and perhaps not surprisingly, it is not disappearance of the bottom features but partial obscuration ("fogging out") of these features that is first seen by people. Disappearance of all bottom features occurs later at higher turbidities. The change in colour of the water towards a bright (milky) appearance is not very obvious until still higher concentrations are achieved suggesting that such colour changes are probably not important in the process of perception of changed water turbidity in optically shallow water bodies. Optically deep water bodies may be quite different in this regard. Here the only cue to changed turbidity is a change in one or more of the attributes of water colour: hue, saturation or brightness, and typically brightness would be the most important of these.

## Conclusions

This preliminary study has identified the approximate level of change in water clarity which is detectable in fairly clear, shallow streams. Over a relatively short time period (minutes) the just noticeable difference was about 10% in terms of reduction in visual clarity. Thus people are highly sensitive to increased turbidity in small clear water streams.

Future work could be aimed at (a) refining definition of JND's in similar situations, (b) identifying sensitivity of JND's to viewing situation and site characteristics and (c) identifying the attribute(s) of water colour/clarity (visual range, hue, brightness) to which observers are most sensitive in different situations.

## Glossary

*absorption* Reduction in radiant flux with distance due to conversion of the light energy to another form (ultimately heat).

*attenuation* Reduction in radiant flux with distance due to the processes of *absorption* and *scattering*.

*brightness* One of the three fundamental attributes of colour. That attribute of colour which varies with the amount of light energy received by the eye.

*clarity* The "transparency" of water. There are two aspects: visual clarity which can be taken as the hydrological range - the distance a perfect black body can be seen horizontally underwater, and the depth to which diffuse sunlight can penetrate vertically into water. Here we are concerned only with visual clarity.

*hue* One of the three fundamental attributes of colour. Often taken as synonymous with "colour" as used loosely. That attribute of colour which varies with the dominant wavelength in the spectrum of light energy and is described as "blue" or "green" for example.

*radiant flux* The most fundamental quantity of light. Measured in watts.

*saturation* One of the three fundamental attributes of colour. That attribute of colour which varies with the spread of the spectrum of light energy and is described as colour purity or (in the inverse sense) the "greyness".

*scattering* Reduction in radiant flux with distance due to change in direction of the light photons.

*turbidity* The relative tendency of a water to scatter light. Informally taken as synonymous with "cloudiness" (lack of visual clarity).

## Acknowledgements

We wish to thank Bob Zuur, formerly of the Waikato Catchment Board, and his assistants for help with site selection and field and laboratory turbidity measurements. Trevor James of the Weed Science Department of MAFTech, Ruakura operated the weed spraying equipment used to deliver the turbid slurry. Christine Smith and Glenys Croker assisted with field sampling and black disk readings and Dave Allen helped with setup of field equipment. Geoff Latimer organised instrumental monitoring and video-recording. Special thanks go to the students of Fairfield College, Hamilton who made up the three panels of observers, and to their teachers Bev Cooper and Graham Hill.

## References

Cragg, A.M.; Smith, D.G. 1989: Perception of bathing water quality. Phase 1: Qualitative studies. Water Quality Centre Internal Report IR 89/02.

Davies-Colley, R.J. 1988: Measuring water clarity with a black disk. *Limnology and Oceanography 33:* 616-623.

Davies-Colley, R.J.; Smith, D.G. 1990: Panel studies of the detectability of change in water colour and clarity induced by discharge of inorganic suspensoids to a small stream. Water Quality Centre Internal Report IR 89/05.

Kirk, J.T.O. 1988: Optical water quality - what does it mean and how do we measure it? *Journal of the Water Pollution Control Federation 60:* 194-197.

Wilcock, R.J.; Davies-Colley, R.J. 1986: Panel tests for evaluating the appearance and odour of the Lower Tarawera River. *New Zealand Journal of Marine and Freshwater Science 20:* 699-708.

Whittemore, R.C.; McKeown, J.J. 1978: A field investigation of human detectability of surface water color changes induced by pulpmill effluent discharge. Paper presented at Purdue University, Indiana, May 10, 1978.

**Table 1. Summary of bottom disappearance*/reappearance* data**

| | Bottom disappearence | | | |
|---|---|---|---|---|
| Depth (m) | c | $y_{BD}$ | Panel | $y_{BD}$/depth |
| 0.36 | 10.41 | 0.46 | 2 | 1.27 |
| 0.73 | 4.69 | 1.02 | 3 | 1.40 |
| | Bottom reappearence | | | |
| 0.73 | 4.81 | 1.00 | 3 | 1.37 |
| | | | Mean = 1.35 | |

* For the 50%-ile

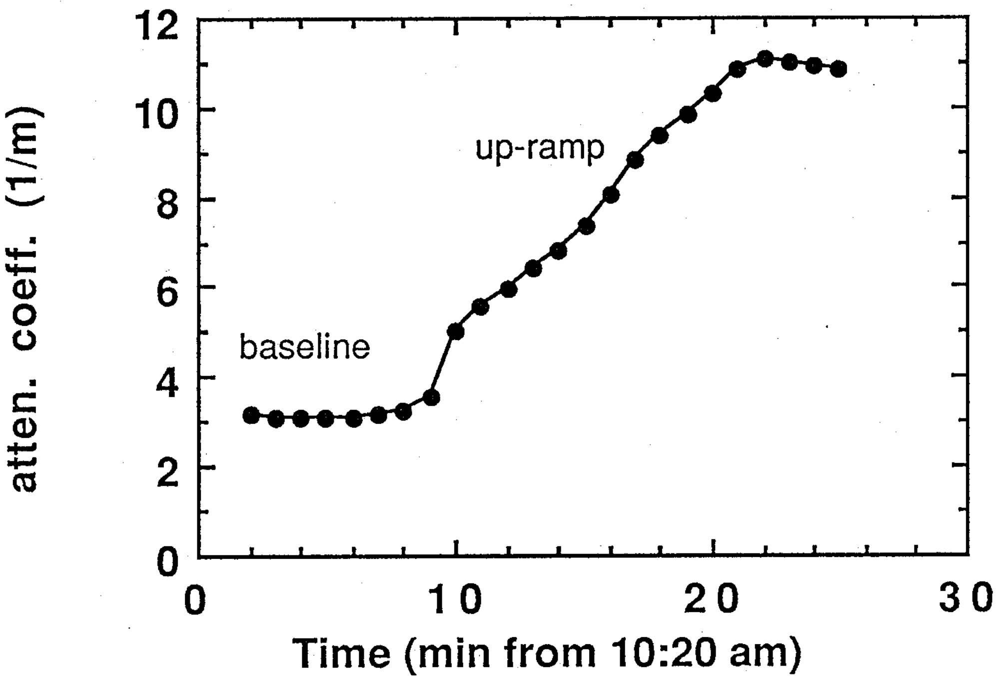

Figure 3. Plot against time (minutes after 10:20 am) of the concentration of suspensoids in the Waingaro stream on 25 March 1988. Concentration is plotted as the beam attenuation coefficient calculated from the chart record of beam transmittance.

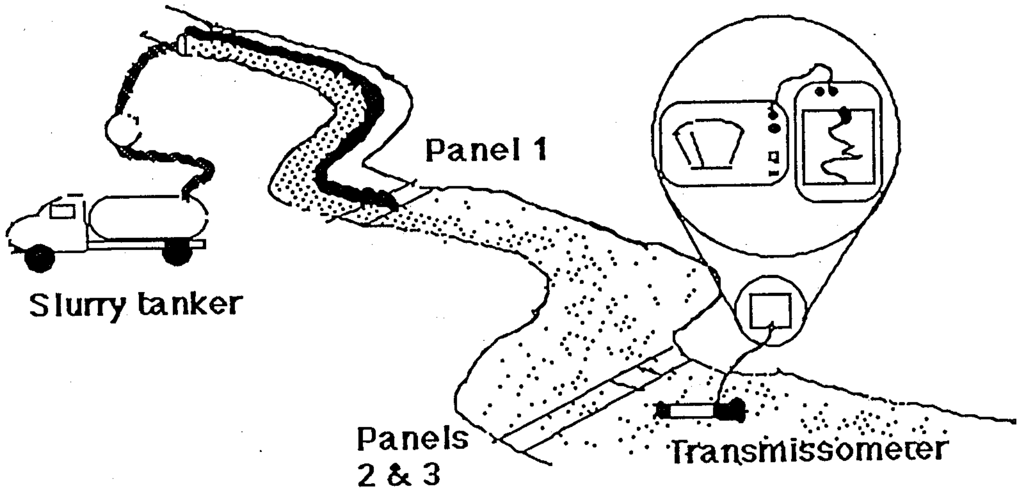

Figure 1. Schematic diagram illustrating the experimental concept. A slurry of intensely light-scattering suspensoids is injected into the stream, initially on one side only of a channel median barrier. Three panels of observers view the stream at three sites. Panel 1 can compare the turbid half of the stream directly with the background appearance whereas Panels 2 and 3 have to rely on their memory of the initial appearance. The concentration of suspensoids is monitored as transmittance with a beam transmissometer.

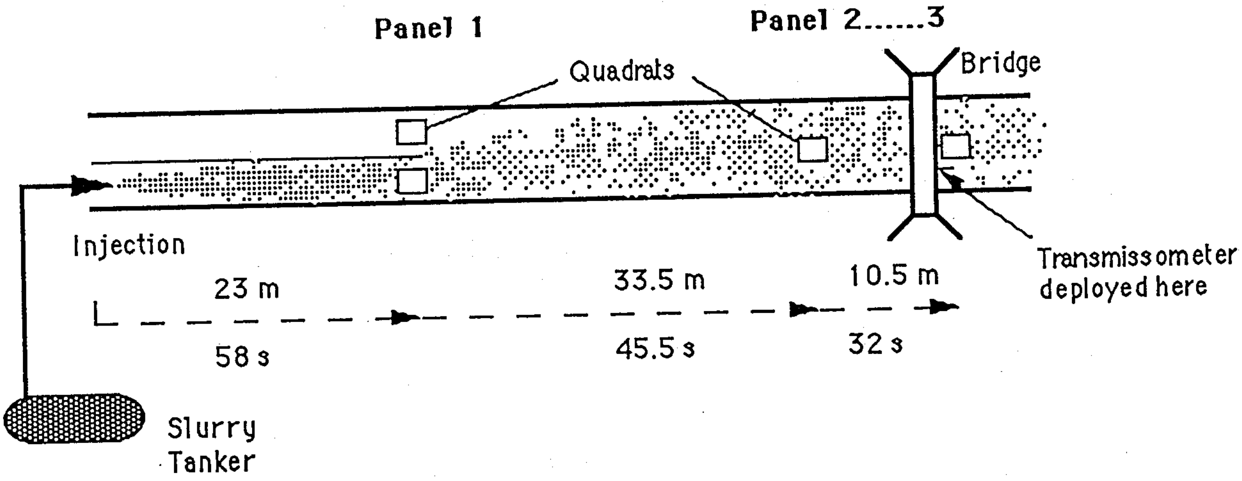

Figure 2. Schematic diagram of the actual experimental setup at Waingaro Stream on the 25 March 1988. Transmittance was measured at the site of an access bridge adjacent to the Panel 3 site. The stream reach between Panels 1 and 2 included a riffle which ensured rapid mixing of the suspensoids across the whole width of flow.

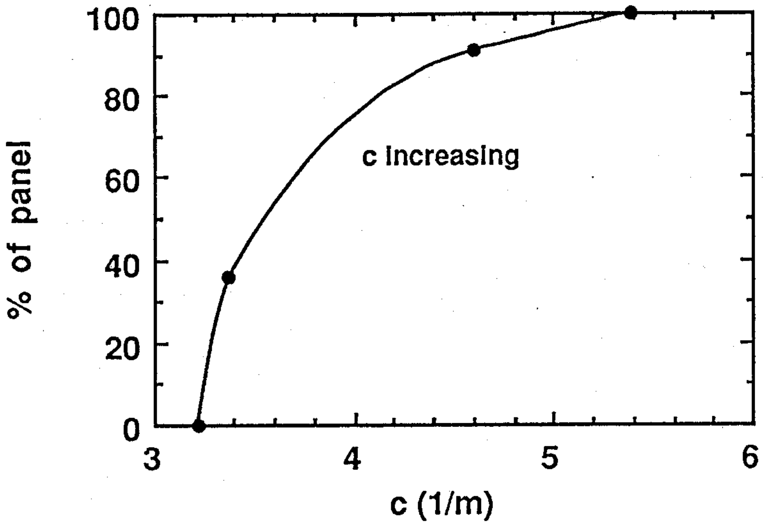

Figure 4. Response curve for Panel 2 showing the proportion of the panel (as a percentage) detecting the change plotted against the beam attenuation coefficient as estimated from the transmissometer time series (Figure 3.) allowing for time of travel.

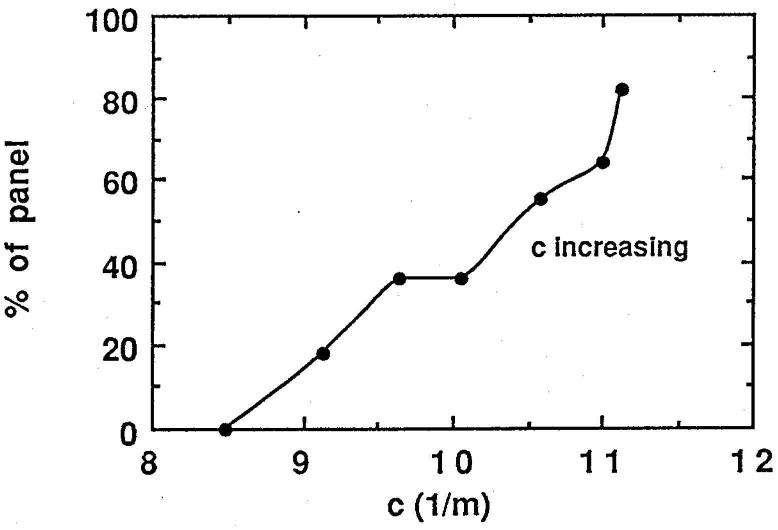

Figure 5. Response curve for Panel 2 showing the proportion of the panel (as a percentage) judging the stream bed to have disappeared plotted against the beam attenuation coefficient as estimated from the transmissometer time series (Figure 3.) allowing for time of travel.

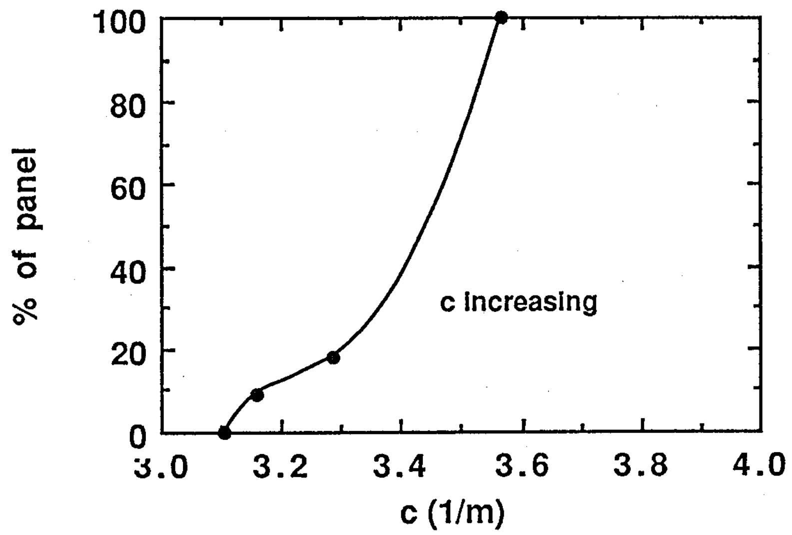

Figure 6. Response curve for Panel 3 showing the proportion of the panel (as a percentage) detecting the change plotted against the beam attenuation coefficient as estimated from the transmissometer time series (Figure 3.).

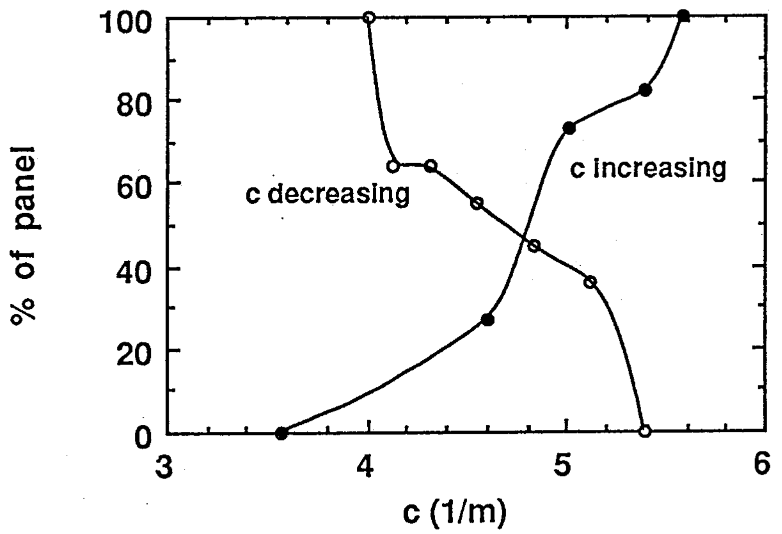

Figure 7. Response curves for Panel 3 showing the proportions of the panel (as percentages) judging the stream bed to have disappeared (or reappeared) plotted against the beam attenuation coefficient as estimated from the transmissometer time series (Figure 3.).