Condensation in Glow-worm Cave, Waitomo, New Zealand

Management guidelines

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ABSTRACT

Understanding cave microclimates is critical for managing a cave environment. A reliable method of measuring condensation within the Glow-worm Cave, Waitomo, New Zealand is described. The results of testing a physical model for predicting condensation rates are reported. Spatial and temporal patterns of condensation in the cave are identified as forming three zones: transitional, entrance, and deep cave zones. Air exchange between the cave and the outside can increase or decrease condensation rates. Condensation is influenced by warm-season and cool-season differences and, more immediately, by opening and closing the solid door at the Upper Entrance to the cave. If wet and dry bulb temperatures of the cave air and rock-surface temperature are known, the dew-point of the air can be estimated. If the rock-surface temperature is below this figure, condensation occurs, if it is above, then no condensation takes place. Cave managers can determine when and where condensation will occur, and how much of the process involves the back-and-forth dynamic process of condensation/evaporation, which inevitably leads to calcite weathering. A table can be used for predicting condensation in the various zones of the cave, and the microclimate can be managed to retain optimum conditions.

Keywords: limestone, karst, caves, glow-worm, cave fauna, ecosystem, microclimate, condensation, tourism, Waitomo Cave, New Zealand

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1. Introduction

Glow-worm Cave, at Waitomo, is one of New Zealand's premier tourist attractions and the most popular cave in Australasia. Co-owned by the Ruapuha Uekaha Hapu and the Crown, represented by the Department of Conservation, the cave has been open to visitors since 1887. Currently, more than 400,000 tourists visit the cave annually, and in summer visitor numbers rise to about 2,000 people per day. Guided tours take place at half-hour intervals, and there are additional visits by other tour groups.

Given the large number of visitors to a small cave of national significance containing important cave fauna, there is a need for careful management to avoid deterioration of the natural cave ecosystem.

2. Cave monitoring and management

Previous studies (de Freitas et al. 1982; de Freitas & Littlejohn 1987) have shown that an understanding of cave microclimate is critical for managing the cave environment. The key is to determine the environmental management techniques that are appropriate to a particular cave condition or environmental state that should prevail. This requires defining and maintaining the desired optimal level or range of environmental conditions, which is assisted by selecting key indicators for monitoring cave conditions. Data on the condition of glow worms and cave microclimate have been collected here since 1980, the latter becoming automated in 1994. In 1997, CO_2 sensors were located in the cave and a visitor-use monitoring system was introduced.

Environmental conditions inside a cave system depend upon the extent and duration of air exchange with the outside through openings. The more entrances there are, and the longer they are open, the greater the influence on the cave interior from outside conditions. Two key ecosystem processes that can be affected by control of air exchange with the outside are rates of condensation and evaporation. These processes are little known in cave systems, but are considered important for two reasons. First, a limiting factor in glow-worm health is moisture stress during times of high evaporation rates—a condition which resulted in temporary closure of the cave in 1979. Second, the condensation/evaporation process leads to weathering of limestone features of caves. Water vapour loaded with carbon dioxide (CO_2) condenses on limestone, causing corrosion, and evaporation leaves residual flaky deposits of calcite. High CO_2 levels induced by large numbers of people in the cave can exacerbate this.

Air exchange with the outside and, therefore, the potential for condensation and evaporation, is affected by air movement through cave entrances. None of this can be reliably assessed and, if necessary, controlled, until condensation/evaporation amounts and rates can be predicted and the processes that determine them understood.

3. Aims of the research

This study, as part of Schmekal (2001), was initiated to devise and test a method of measuring the continuous process of vapour transfer in the form of condensation and evaporation in the Glow-worm Cave. This information would then allow development of a physical model for predicting evaporation and condensation rates in the cave, which in turn would assist management in controlling air exchange with the outside. The work has implications for the management of other caves, increasing the understanding of both natural processes and the impact of visitors.

4. Methods and test results

There is no standard method of measuring condensation, only devices for measuring dew. Because of this, measurement devices had to be constructed that would function in a cave environment. Condensation was measured using condensation sensors connected to an electronic data logger. A condensation sensor consists of two sets of parallel wires mounted on a flat surface, so that when condensation occurs the resistance between the wires changes. The sensors used for this research consisted of multiple fingers of interleaved conductive tracks to provide greater sensitivity. The sensors were extensively tested in the laboratory and each sensor was individually calibrated.

To calculate rates of condensation, a physical model was devised. The model was tested by comparing the measured rates with the calculated rates. The results showed that the model worked well. Condensation is a function of the vapour gradient between the cave rock and cave air. The temperature gradient between the rock surface and dew-point temperature of the cave air is in part a function of the condition of the air outside, and varies over the day and with the seasons. Changes of rock-surface temperature were observed to change gradually with the changing seasons and no short-term changes were observed. Air exchange with the outside can increase or decrease condensation rates. For example, airflow can increase condensation rates by transporting warm, moist air into the cave.

The test results also show that condensation rates varied spatially and temporally in the cave. Longer-term as well as short-term temporal variations of condensation rates were observed. Over a period of 24 hours, condensation rates were higher during the daytime when air temperatures rose. Seasonal

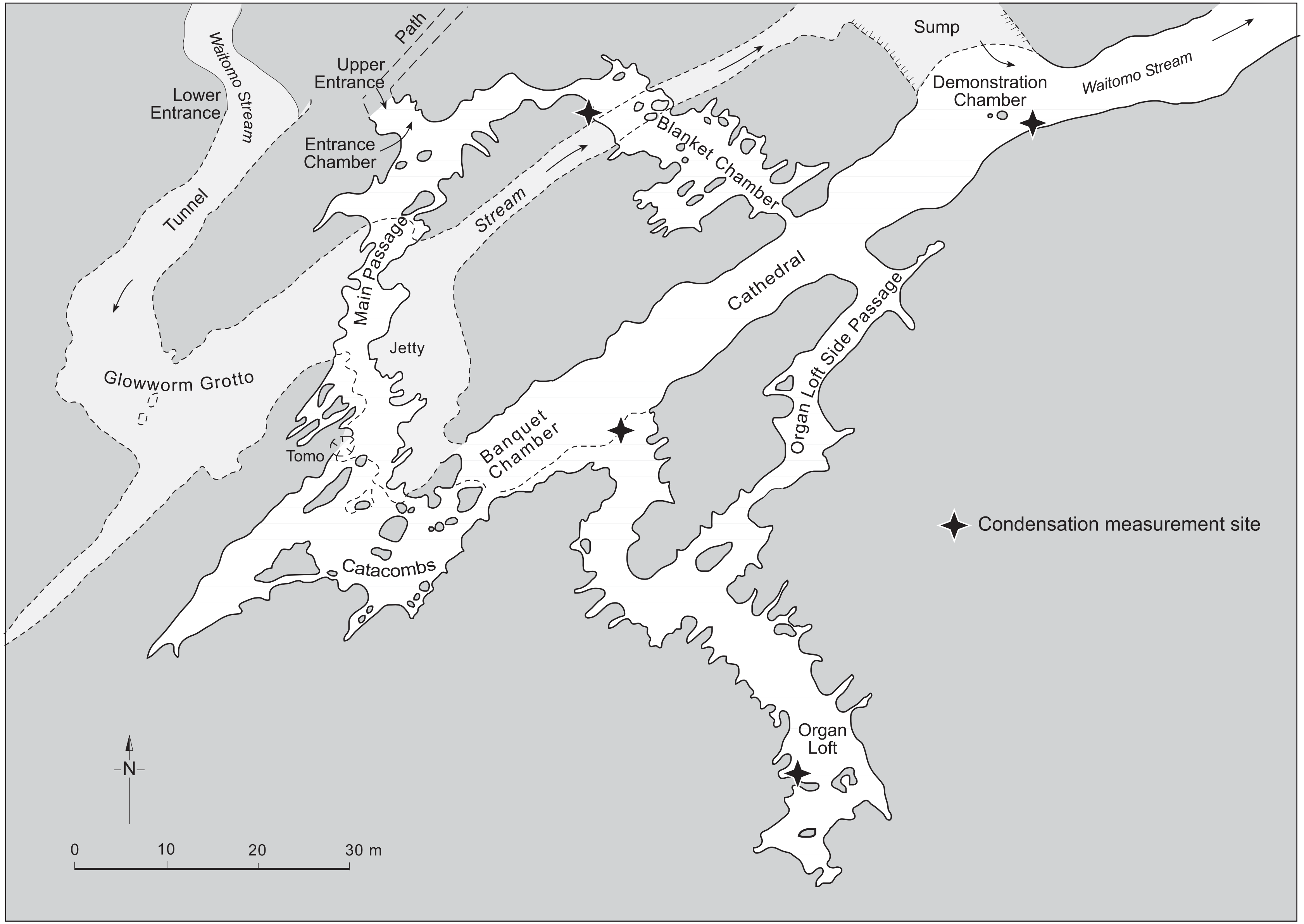

Figure 1. Glow-worm Cave, Waitomo, showing condensation measurement sites, and named cave features (after fig. 3.6 in Schmekal 2001). The cave outline is based upon surveys by L.O. Kermode (New Zealand Geological Survey, DSIR 1974), and others.

changes are large, with higher condensation rates occurring in the warm months. At the Organ Loft (Fig. 1), for example, a continuous condensation process was observed, while at the Cathedral, condensation occurred only during the day in summer. At all times in the Organ Loft, air temperature exceeds rock-surface temperature. During the warm months of the year high condensation rates were observed and no evaporation occurred. In the cooler months condensation processes continued, but the rate decreased. The Cathedral and Banquet Chambers have similar microclimates and the same condensation patterns. During the warm months, condensation occurred during the daytime when cave air temperature exceeded rock-surface temperature. In the transitional months and cool season, condensation rates dropped back until finally no condensation was observed.

The Blanket chamber was the site most influenced by the air outside. Conditions could change quickly. During the warm months condensation occurred in both day and night-time, whenever the cave air temperature exceeded rock-surface temperature. Condensation rates and evaporation rates here were high, and a constant wetting and drying of the cave walls occurred. In winter, condensation rates dropped. This occurred during night-time when the warm cave air rose to the upper level of the cave. During day-time evaporation occurred shortly after the cave door was opened.

5. Management guidelines

Understanding the condensation processes is important because the condensation/evaporation process leads to weathering of limestone features of the cave. Water vapour loaded with CO_2 condenses on the limestone leading to corrosion, while evaporation leaves residual flaky, unsightly deposits of calcite. High CO_2 levels in the cave brought about by the presence of large numbers of visitors may exacerbate this. Also, air exchange with the outside and, therefore, the potential for condensation and evaporation, is affected by air movement to and from the cave through entrances. However none of this can be reliably assessed, and then if necessary controlled, until amounts and rates of condensation-evaporation can be predicted and the processes that determine them understood.

The results of this research allow cave managers to determine when condensation will occur and where it will occur. The information also enables the cave manager to determine how much of the process involves the back-and-forth dynamic process of condensation followed by evaporation of condensate, which inevitably leads to calcite weathering.

Given that condensation is a function of air temperature, rock-surface temperature and moisture content of the air, air temperature is easiest to control. Thus, under certain conditions, changing the temperature of the air in the cave can change the condensation rate. Depending on moisture content of the air, condensation will occur if the air temperature is lower than the rock temperature. If the air temperature gradient between the rock surface and air is

TABLE 1. GUIDELINES TO PREDICTING IF AND WHEN CONDENSATION IS LIKELY TO OCCUR IN THE GLOW-WORM CAVE. (See text for details.)

DRY BULB (°C)	DEPRESSION OF WET BULB (°C)						
	0	0.1	0.2	0.3	0.4	0.5	0.6
18.0	20.63	20.43	20.24	20.05	19.86	19.67	19.47
17.9	20.50	20.31	20.11	19.92	19.73	19.54	19.35
17.8	20.37	20.18	19.99	19.79	19.60	19.41	19.22
17.7	20.24	20.05	19.86	19.67	19.48	19.29	19.10
17.6	20.11	19.92	19.73	19.54	19.35	19.17	18.98
17.5	19.99	19.80	19.61	19.42	19.23	19.04	18.86
17.4	19.86	19.67	19.43	19.29	19.11	18.92	18.73
17.3	19.74	19.55	19.36	19.17	18.98	18.80	18.61
17.2	19.61	19.42	19.24	19.05	18.86	18.68	18.49
17.1	19.49	19.30	19.11	18.93	18.74	18.56	18.37
17.0	19.37	19.18	18.99	18.81	18.62	18.44	18.25
16.9	19.24	19.06	18.87	18.69	18.50	18.32	18.14
16.8	19.12	18.94	18.75	18.57	18.38	18.20	18.02
16.7	19.00	18.82	18.63	18.45	18.26	18.08	17.90
16.6	18.88	18.70	18.51	18.33	18.15	17.96	17.78
16.5	18.76	18.58	18.39	18.21	18.03	17.85	17.67
16.4	18.64	18.46	18.28	18.10	17.91	17.73	17.55
16.3	18.52	18.34	18.16	17.98	17.80	17.62	17.44
16.2	18.40	18.22	18.04	17.86	17.68	17.50	17.32
16.1	18.29	18.11	17.93	17.75	17.57	17.39	17.21
16.0	18.17	17.99	17.81	17.63	17.45	17.28	17.10
15.9	15.06	17.88	17.70	17.52	17.34	17.16	16.99
15.8	17.90	17.76	17.58	17.40	17.23	17.05	16.88
15.7	17.83	17.65	17.47	17.29	17.12	16.94	16.76
15.6	17.71	17.53	17.36	17.18	17.00	16.83	16.65
15.5	17.60	17.42	17.24	17.07	16.89	16.72	16.55
15.4	17.49	17.31	17.13	16.96	16.78	16.61	16.44
15.3	17.37	17.20	17.02	16.85	16.67	16.50	16.34
15.2	17.26	17.09	16.91	16.74	16.57	16.39	16.22
15.1	17.15	16.98	16.80	16.63	16.46	16.29	16.11
15.0	17.04	16.87	16.69	16.52	16.35	16.18	16.01
14.9	16.93	16.76	16.59	16.41	16.24	16.07	15.90
14.8	16.82	16.65	16.48	16.31	16.14	15.97	15.80
14.7	16.72	16.54	16.37	16.20	16.03	15.86	15.69
14.6	16.61	16.44	16.27	16.10	15.93	15.76	15.59
14.5	16.50	16.33	16.16	15.99	15.82	15.65	15.48
14.4	16.39	16.22	16.05	15.89	15.72	15.55	15.38
14.3	16.29	16.12	15.95	15.78	15.61	15.45	15.28
14.2	16.18	16.01	15.85	15.68	15.51	15.34	15.18
14.1	16.08	15.91	15.74	15.58	15.41	15.24	15.08
14.0	15.97	15.81	15.64	15.47	15.31	15.14	14.98
13.9	15.87	15.70	15.54	15.37	15.21	15.04	14.88
13.8	15.77	15.60	15.44	15.27	15.11	14.94	14.78
13.7	15.67	15.50	15.33	15.17	15.01	14.84	14.68
13.6	15.56	15.40	15.23	15.07	14.91	14.74	14.58
13.5	15.46	15.30	15.13	14.97	14.81	14.64	14.48
13.4	15.36	15.20	15.03	14.87	14.71	14.55	14.39
13.3	15.26	15.10	14.94	14.77	14.61	14.45	14.29
13.2	15.16	15.00	14.84	14.68	14.51	14.35	14.19
13.1	15.07	14.90	14.74	14.58	14.42	14.26	14.10
13.0	14.97	14.80	14.34	14.48	14.32	14.16	14.00

made smaller, condensation rates will decrease, and they will increase if the gradient becomes larger. Under certain conditions, opening or closing the door at the Upper Entrance can influence air temperature inside the cave. The effect will depend on the outside temperature and humidity, and on rates of air exchange with the outside. Condensation will occur when the dew-point temperature of the cave rock is lower than the dew-point temperature of the cave air.

Table 1 can be used as a guideline for predicting if and when condensation is likely to occur in the Glow-worm Cave. By measuring wet and dry bulb temperature of the cave air and rock-surface temperature, the dew-point gradient can be estimated. The values shown in columns two to eight in Table 1 are dewpoint temperatures. A particular dewpoint value is found by reading along from a measured dry bulb air temperature (in the far left or first column) to a measured wet bulb depression (i.e. measured dry bulb minus measured wet bulb air temperatures) shown in the columns labelled 0°C to 0.6°C. If the rock-surface temperature is below this figure condensation occurs, if it is above, evaporation takes place.

The measurement sites chosen for this study (see Fig. 1) were selected to represent various zones within the cave. The management guidelines are based on the observations made at these sites and are generalised for these areas they represent. The Organ Loft represents the deep cave zone, the Cathedral and Banquet Chamber the transitional zones, and the Blanket chamber is a near-entrance zone. Guidelines on the entrance area are based on observations only as no condensation sensors were installed in this area.

5.1 WARM SEASON SITUATION

The transitional zone is strongly influenced by temperature and moisture conditions of the outside air. Condensation occurs during the day when cave air temperatures rise. During the night the cave air temperature falls and evaporation occurs. To increase condensation rates, the cave door needs to be opened whenever outside temperatures are higher than cave air temperatures: summer flow will then occur, the cave air will warm up, and rates will increase. To reduce condensation rates or induce negative rates, the cave door needs to be kept open when outside air temperatures are lower than the cave air temperature.

To increase condensation rates in the near-entrance zone, the Upper Entrance door needs to be left open when outside air temperature exceeds cave air temperatures during the day and also during warm nights, when minimum outside air temperatures are higher than the temperatures of the cave rock-surface. To reduce condensation rates the opposite needs to be done: as soon as outside temperature is higher than cave air temperatures the door should be shut.

In the deep cave zone, conditions leading to continuous condensation rates prevail. The ventilation experiments showed that opening or shutting the cave door has no influence on the condensation rates in this part of the cave. However, the door experiment was over a period of three days, which is a relatively short period. If the door was to be kept open for a longer period, condensation rates may eventually change deep in the cave.

5.2 COOL SEASON SITUATION

During the cold months of the study period no condensation was observed at the transitional zone. Constant evaporation will take place as long as water is available at the rock surface. Cave air temperatures are lower than rock-surface temperatures. Condensation rates can only increase during mild winter days when outside temperatures exceed cave air temperatures. To increase condensation, the Upper Entrance door should be opened (or closed to reduce it).

In the near-entrance zone, condensation takes place during the night when warmer cave air rises to the upper level of the cave. In the morning when tour groups arrive, cold air enters the cave and evaporation takes place. As soon as the door is permanently closed for the night the condensation process starts again. To increase or stabilise condensation rates, the door should be kept shut as much as possible during the day. It should be noted that this condensation pattern was only observed to occur in the Blanket Chamber. The immediate entrance area and the Main Passage stayed dry during the entire cold period.

In the deep cave zone there is less condensation than in the warm season. However, net condensation is still positive, and condensation water will accumulate and eventually will build-up and run down the cave wall.

6. References

de Freitas, C.R.; Littlejohn, R.N. 1987. Cave climate: assessment of heat and moisture exchange. *Journal of Climatology* 7: 553–569.

de Freitas, C.R.; Littlejohn, R.N.; Clarkson, T.S.; Kristament, I.S. 1982. Cave climate: assessment of airflow and ventilation. *Journal of Climatology* 2: 383–397.

Schmekal, A.A. 2001. Condensation as a microclimate process: measurement and analysis in the Glow-worm Cave, New Zealand. Unpublished MSc Thesis, Department of Geography, University of Auckland. 82 p.