Spatial Data Analysis as a Means of Risk Assessment of Schistosomiasis in Sichuan Province, China

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Abstract

Accurate measurements of exposure are critical to developing adequate public health intervention with human schistosomiasis. Current exposure measurements, which include duration of water exposure, time of water exposure, and body surface area (BSA) exposed, do not show any significant relationship between intensity of infection (eggs per gram of stool, epg) and water contact data. To address this discrepancy, ArcGIS and ArcHydro tools were used to generate a continuous ditch network and flow direction map of Minhe village in Sichuan Province, China and examine the effect of including cercarial concentrations in current exposure models. One "space matters" map was based on actual snail data collected by Sichuan Institute of Parasitic Disease (SIPD) and Spear's Research Group based in UC Berkeley's School of Public Health; another "space doesn't matter" map was based on an assumed random distribution of snails and cercaria across the ditch network. While statistical analysis is not referenced here, current results indicate that using actual snail data and cercarial concentration potentially depict a pattern of 'hot-spots,' or areas of higher infection risk, as opposed to risk maps based on randomization which assume an even distribution of risk. Such data suggests there may be more effective ways in advising infected populations as to how they can lower or eliminate their infection rates. Accurate knowledge of high-risk sites also allows for more efficient and focused public health interventions. Further statistical study of the contribution of cercarial concentrations to schistosomiasis exposure models should be conducted.

Introduction

Human schistosomiasis is a water-borne, parasitic disease that affects 200 million people worldwide, and threatens 400 million more in at least 76 countries (WHO, 1993). The schistosome lifecycle begins with the sexual mating of adult worms in the blood vessels of a vertebrate host. The female schistosome will release eggs into the host's bloodstream; some of these eggs will subsequently be taken up into the intestines and excreted into the water via the feces. Once in the water, these eggs hatch and release miracidia, a free-swimming larvae, which then seek out an intermediate snail host to infect. Following approximately six to ten weeks of asexual reproduction in these snails, a tailed, free-swimming larvae called cercaria exit the snails and undergo water transport until they find suitable vertebrate hosts. Cercaria will penetrate the skin of the host and mature into adult worms, thus completing the infectious cycle (Mazle et al, 1998).

Since water is recognized as the main route of transmission for schistosomiasis, several studies have looked at water contact patterns and how they may be associated with infection intensity (measured in eggs per gram, epg, of stool sample) seen in regions endemic to disease. Water contact patterns include agricultural, recreational, and domestic activities. Such exposure to water is thought to predict the potential parasite burden in vertebrate hosts. The accuracy to which current exposure measurements assess infection intensity differs depending on the model of exposure used. Each study has used a different exposure model standard by which they translated observations and survey data regarding water contact patterns into levels of exposure. For example, in their study of Brazil, Freidman *et al* (2001) compared several calculations of individual exposure. By demonstrating the necessity of frequency and duration data in exposure assessments, this study suggested that not all measures of exposure will yield identical results: some models assess risk with greater accuracy. Since accurate exposure assessments potentially lead to good intervention designs, we would expect infection intensity to be associated with results from water contact surveys. These surveys provide detailed information regarding the duration and frequency of an individual's contact with potentially contaminated water. However, Friedman's study makes no mention of significant correlations between such water exposure and infection intensity.

In a similar study comparing the effectiveness of direct observation and surveys in collecting water contact data, Gazzinelli *et al* (2001) defined exposure as being the product of frequency of a particular water contact activity (i.e. – washing dishes, fetching water, etc), the mean duration in minutes of the activity, and the average percentage body surface area (BSA) exposed to the water contacts by activity. Frequency was determined by the number of water contacts by activity for each individual.

Mean duration was calculated by first taking the difference between water entry and exit times for the activity, and then taking the mean of the difference. BSA exposure was determined by a burn chart (Murahovshi, 1997), and then converted into a percentage based on the Kloos and Lemma method (1980). This exposure model was described in terms of total body minutes (TBM). While significant differences were found in both water contact frequencies and duration of activities between gender, however, no strong correlation was found between TBM by activity and infection intensity.

Scott *et al.* (2003) also determined that water contact is not a stand alone measure of exposure for schistosomiasis. While acknowledging that an individual's duration of contact, BSA exposed, and even time of day were likely contributors to overall risk of infection, they observed no correlation between (re)infection intensity and exposure models, even when designed to incorporate age, sex, and/or village. Models included in the study are as follows: frequency of water contact activity, total duration of activity, duration x BSA exposed, and duration x BSA x time of day that activity occurred. Total duration (min/day) was multiplied by weighting factors which accounted for differences in cercaria viability per season. The article suggests that the apparent lack of relationship between (pre)treatment exposure and infection intensity could be resultant from "insufficient documentation of water contact" or "inadequate understanding of how water contact translates into exposure."

This study suggests that one possible reason for the discrepancy between water contact survey results and infection intensity is the exclusion of cercarial concentration measurements in current exposure models. Even if a particular water activity were to be repeated for extended periods of time throughout the day in the same location, if there are no cercaria in the water, there will be no infection. Similarly, even a brief amount of time spent in highly contaminated water could result in high infection. As the exposure model currently stands, presence of cercaria makes no difference in the level of exposure or risk. This indicates the possibility that the presence of cercaria needs to be included for a more accurate measure of exposure.

Another potential pitfall of current exposure models could be the implicit assumption that snail hosts and cercarial concentrations are constant across these endemic regions. Once again, however, the discrepancy between water contact data and infection intensity points to the possibility that these snails and cercaria are unevenly distributed in a region's water sources, and that an exposure model such as the following might be more accurate.

This project proposes to demonstrate the effect of including nonrandom distributions of cercarial concentrations in an exposure model through the use of GIS tools. Also, this project will analyze the effect of water flow on cercarial concentrations using ArcHydro tools. By using real networks, actual snail data, proportionally estimated cercarial inputs and decay, and hypothetical activity scenarios, the goal is to determine the value of including a cercarial density term in exposure models of schistosomiasis. In turn, these scenarios could suggest more effective ways of advising infected populations as to how they can lower or eliminate their infection rates. These could include avoidance of certain 'hot spots' of infection, combination of exposure precautions (i.e. – less time spent in certain 'hot spots,' less BSA exposed in certain 'hot spots', etc.).

Methods

Ditch network

GPS-generated images of Minhe's irrigation ditch network show the entire area of possible risk, given that the ditch is a primary infection site. Maps with general direction of water flow were also made available, although some extrapolation was necessary in order to completely determine downstream flow.

Snail data

Snail data was taken using a *quat* laid down every 10 meters along Minhe's ditch network. A quat is a boxed off area, approximately .11m^2, that lays directly along the ditch network. Measurements per quat included snail density and a cercarial infection rate. The latter allows for calculation of expected cercarial output rate form that particular quat. Previous studies have assumed a proportional relationship between mean cercarial risk and snail infection at these locations. However, cercarial input from upstream water flow has not been accounted for in the consideration of cercarial concentration.

Accumulation of Cercaria

To transfer these ditch networks into a framework usable by ArcHydro, a tabular system containing all the relevant data mentioned above is applied in ArcGIS. This data is then imported and applied using an ArcHydro framework: HydroEdge feature class is the ditch network itself *(Figure 1),* HydroJunction feature class includes the junction points along the networks *(Figure 2),* and MonitoringPoint feature class includes the snail points *(Figure 3).* Using these classes, ArcHydro can calculate the length downstream and direction of water flow along the network itself. To create a continuous ditch network, the available GPS-generated maps of different segments of Minhe's ditch network were traced and connected using ArcMap 8.3 This was done in hopes of eliminating potential errors or lapses in the original GPS-generated images. Otherwise, gaps or overlapping areas in the maps confuse the ArcHydro software when trying to determine the definite direction of water flow. This directly affects the calculation of cercarial load accumulation, since the cercaria only move with the water flow.

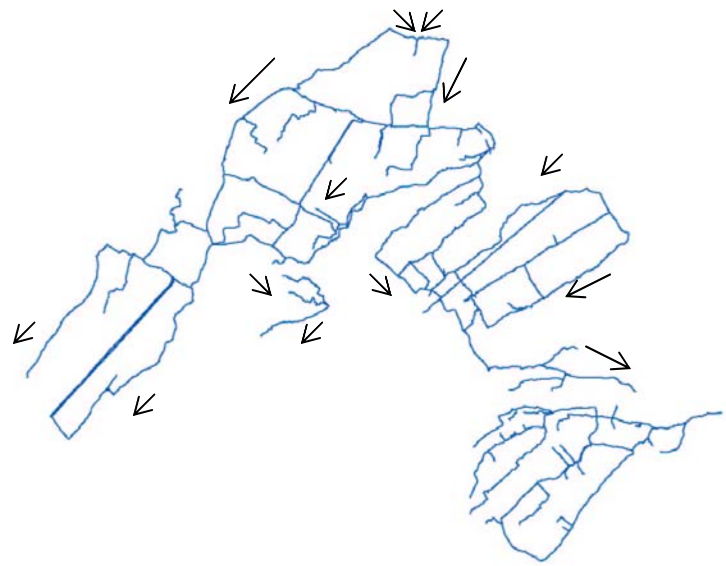

Figure 1. HydroEdge. The ArcHydro version of Minhe's ditch network**.**

Arrows on Figure 1 indicate the direction of water flow, as discussed above. For time constraint purposes, analysis was only completed on the larger portion of the ditch network. Analysis on the remaining portion can be completed in the exactly the same manner as described below.

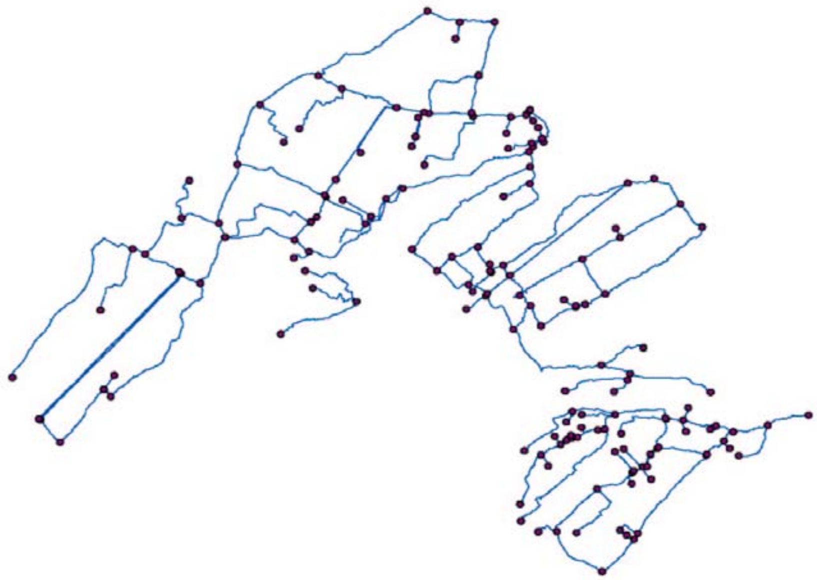

Figure 2. HydroEdge with HydroJunctions.

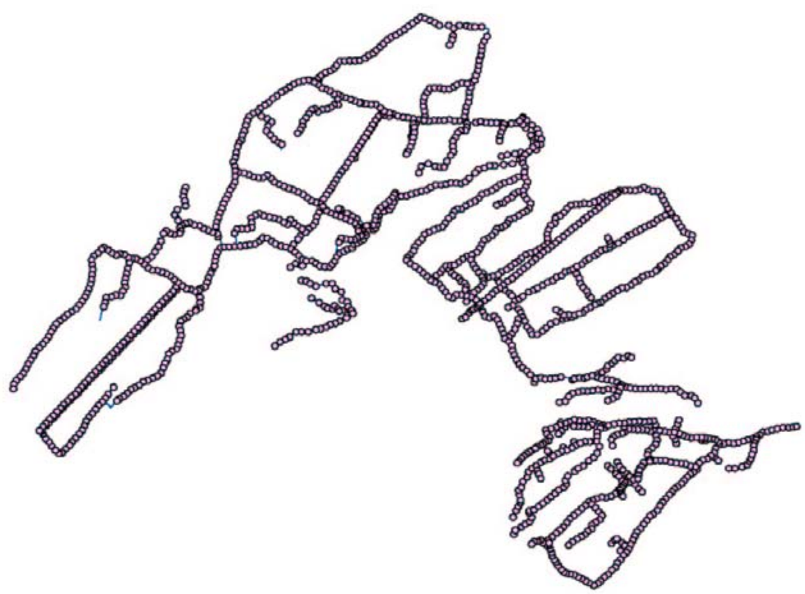

Figure 3. HydroEdge with MonitoringPoints.

Once the traced map of Minhe's complete ditch network was established in ArcHydro, each MonitoringPoint was then assigned a unique HydroID number for easy identification. In the MonitoringPoint attribute table, a column named 'Cercaria' were created. Using an approximate infection rate of 0.49% per quat, and a burden of 936 cerc/snail, an estimated cercarial output per

MonitoringPoint was calculated using an Excel spreadsheet. Each MonitoringPoint received a particular amount of cercaria, and in turn, passed a certain amount downstream to the next MonitoringPoint. Also taken into consideration when calculating output was the effect of cercarial decay due to rough water transport or cercaria sticking to the canal walls. Decay was based on research indicating that about 10% of an original cercarial concentration will still be viable after traveling 400m (Appendix, Tables 2-4). HydroJunctions served as the accumulation points for upstream MonitoringPoints.

The HydroJunction values were entered into the ArcHydro attribute column 'Cercaria', based on known water flow directions and snail densities ('Snail No') at each location. The labeling feature within ArcGIS was then set to Bar/Column for the 'Cercaria' attribute of the MonitoringPoint feature (*Figure 4)*. Therefore, the height of each bar reflects the nonrandom cercarial value at each MonitoringPoint along the ditch network. In order to reduce 'noise' on the map, only the bars at each HydroJunction appears on *Figure 5*.

The same process was applied to the random distribution map. However, instead of using known values of snail densities, identical snail densities were entered into the 'Original Snail' column for each MonitoringPoint (Appendix, Table 1). Again, HydroJunctions served as the accumulation points. The purpose of this trial run was to simulate the scenario where risk (i.e. – cercarial output) was evenly distributed across the ditch network.

Results

Figure 4 shows the results of the "space matters" map, based on calculations using real snail densities. The height of the bars indicate the level of cercaria concentrations found at a given HydroJunction. Actual accumulated values can be found in Table 5 of the Appendix. Similarly, Figure 5 shows the results of the "space doesn't matter" map, based on calculations using an even distribution of snail density and cercarial output per quat.

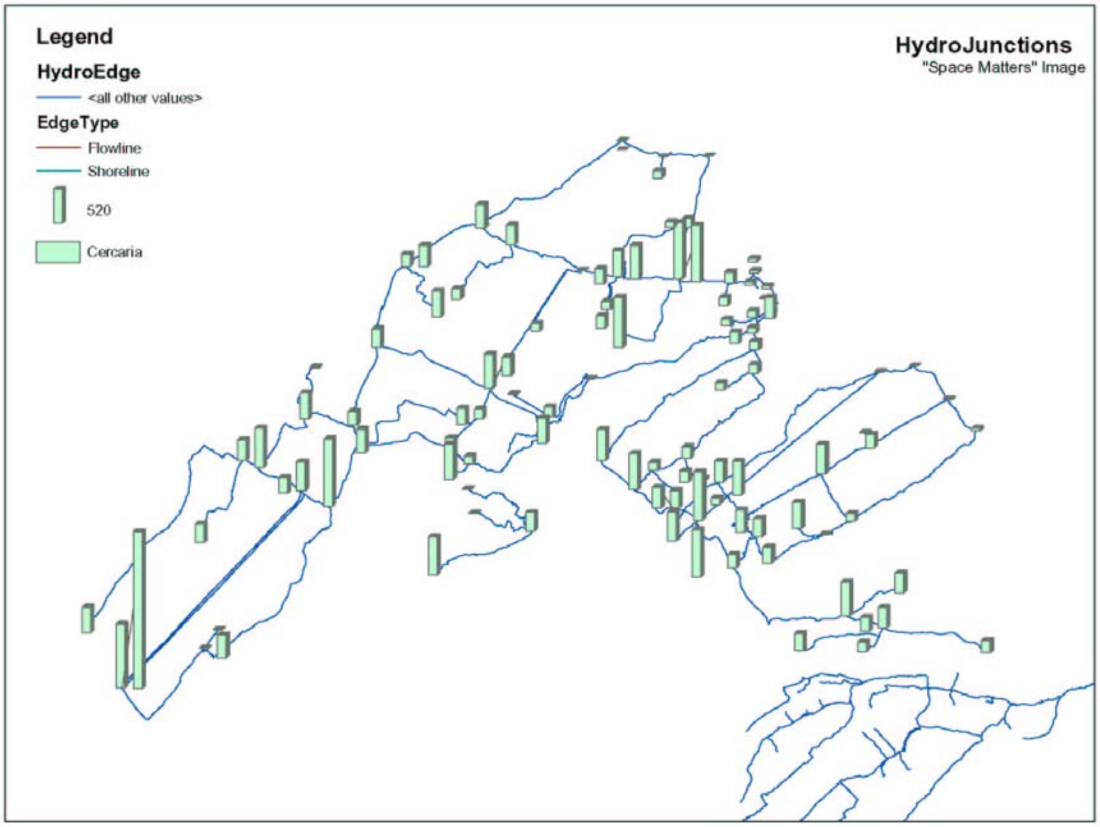

Figure 4. HydroJunction concentrations for a “space matters” map.

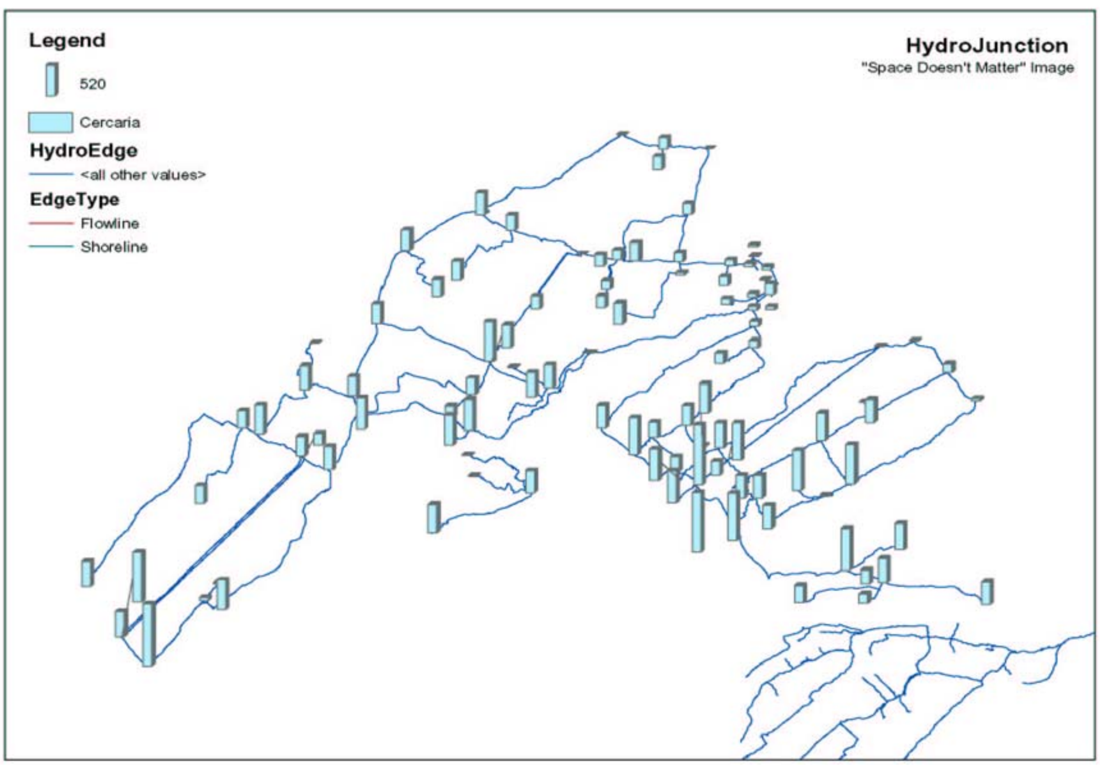

Figure 5. HydroJunction concentrations for a “space doesn’t matter map.”

Discussion

Given unexpected setbacks, statistical analysis comparing the "space matters" and "space doesn't matter" map could not be completed. However, in simple observation of the results, one can see potential 'hot-spots' that appear on the "space matters" map, which are not quite as dramatic on the "space doesn't matter" map.

An important detail to note from this study is that it only examined the qualitative distribution of risk as a function of snail density and cercarial concentrations. Future research should include the consequence of random and non-random movement of humans across the ditch network as well. Using the results from this study, current individual exposure models could incorporate a spatial element, as demonstrated in Equation 1:

$$E_i = \Sigma\Sigma e_k \tau_{jk}(t_i) c_j(t_i)$$

Equation 1. Exposure model including cercarial concentration.

where E_i measures the exposure of an individual on a day t_i in cercaria/day, τ_{jk} is the duration (hrs/day) that activity 'k' occurs at location 'j', and c_j is the cercarial concentration per m^2 of contacted water at location 'j'. This individual exposure assumes 'm' locations, and then sums over p_k, the number of locations activity 'k' is carried out (Spear *et al*, 2002). This model takes the exposure from an individual's activity in one particular place, with the inclusion of cercarial concentration at that site, and adds it to the individual exposure at a second site, and so on. Thus, there is one summation over all activities, and another over visited locations, given potentially variant cercarial concentrations. Given the extensive individual water contact data available from previous and ongoing studies, the results of this research potentially offer a more encompassing estimate of risk.

One question to consider is whether the apparent 'hot-spots' are truly significant, or simply due to effect of downstream accumulation. A problem with determining this factor is the remaining challenge in measuring cercarial concentrations in the water. The most frequently used method, mouse bioassay, is both time-consuming and costly to conduct (Spear *et al,* 2002). Another aspect still unaccounted for is the effect of water speed on cercarial movement. Since locals manually monitor the water flow by opening and closing certain floodgates, significant variations could arise at any given time throughout the irrigation ditch. These variations could in turn effect the cercarial concentration loads that are passed and received.

Also, the distribution of cercaria through the ditch network was originally to be done using a ArcHydro schematic model, which would automatically calculate passed and received values in the ditch network. The process of applying the schema would be based on Whiteaker's ArcHydro Tutorials cited below (Whiteaker and Goodall, 2003). However, it was discovered that no ArcHydro tool existed which could split the bacterial load at a point of canal divergence. One possible venture for future research, wheter in public health or other fields of study, would be to code a computer program which could run this particular processing operation within ArcHydro, so as to avoid the need for manual calculations.

Despite this study's lack of statistical analysis, the pattern of higher concentrations in certain areas along the "space matters" map versus the "space doesn't matter" map confirms the need for further research into this area. If significant differences between the concentrations between the above maps do in fact exist, then intervention plans for schistosomiasis may stand to be administered more effectively. Similarly, if no significant differences appear, then it lends evidence that cercarial concentrations can be eliminated as a potential factor for the discrepancy between water contact surveys and infection intensity.

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Software Programs

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ArcHydro GIS for Water Resources. ESRI Press (2002). 88871

Appendix

SnailNo	InfRate	CercBurden	TotCercPerQuat	*HydroID*	Original Snails	Normal Distribution	InfRate	CercBurden	TotCercPerQuat
4	0.0049	936	18.34	1	4	4	0.0049	936	18.35
4	0.0049	936	18.34	2	4	4	0.0049	936	18.35
7	0.0049	936	32.09	3	7	4	0.0049	936	18.35
2	0.0049	936	9.17	4	2	4	0.0049	936	18.35
1	0.0049	936	4.58	5	1	4	0.0049	936	18.35
5	0.0049	936	22.92	6	5	4	0.0049	936	18.35
3	0.0049	936	13.75	7	3	4	0.0049	936	18.35
16	0.0049	936	73.36	8	16	4	0.0049	936	18.35
20	0.0049	936	91.70	9	20	4	0.0049	936	18.35
5	0.0049	936	22.92	10	5	4	0.0049	936	18.35
5	0.0049	936	22.92	11	5	4	0.0049	936	18.35
28	0.0049	936	128.37	12	28	4	0.0049	936	18.35
12	0.0049	936	55.02	13	12	4	0.0049	936	18.35
4	0.0049	936	18.34	14	4	4	0.0049	936	18.35
5	0.0049	936	22.92	15	5	4	0.0049	936	18.35
2	0.0049	936	9.17	16	2	4	0.0049	936	18.35
1	0.0049	936	4.58	17	1	4	0.0049	936	18.35
4	0.0049	936	18.34	18	4	4	0.0049	936	18.35
2	0.0049	936	9.17	19	2	4	0.0049	936	18.35
4	0.0049	936	18.34	20	4	4	0.0049	936	18.35
1	0.0049	936	4.58	21	1	4	0.0049	936	18.35
38	0.0049	936	174.22	22	38	4	0.0049	936	18.35
1	0.0049	936	4.58	23	1	4	0.0049	936	18.35
2	0.0049	936	9.17	24	2	4	0.0049	936	18.35
1	0.0049	936	4.58	25	1	4	0.0049	936	18.35
5	0.0049	936	22.92	26	5	4	0.0049	936	18.35
3	0.0049	936	13.75	27	3	4	0.0049	936	18.35
5	0.0049	936	22.92	28	5	4	0.0049	936	18.35
2	0.0049	936	9.17	29	2	4	0.0049	936	18.35
2	0.0049	936	9.17	30	2	4	0.0049	936	18.35
2	0.0049	936	9.17	31	2	4	0.0049	936	18.35
1	0.0049	936	4.58	32	1	4	0.0049	936	18.35
1	0.0049	936	4.58	33	1	4	0.0049	936	18.35
1	0.0049	936	4.58	34	1	4	0.0049	936	18.35
3	0.0049	936	13.75	35	3	4	0.0049	936	18.35
2	0.0049	936	9.17	36	2	4	0.0049	936	18.35

Table 1. Averages for Calculations of Total Cercaria Per Quat. Each MonitoringPoint and HydroJunction are associated with a particular snail density. This density is multiplied by an estimated infection rate and cercarial burden expected from any given infective. The TotCercPerQuat are the values entered in ArcHydro. (Only HydroIDs 1-36 shown here. Actual ID range: 1-1483)

Tables 2-4. Sample calculation of passed and received cercarial concentrations at each MonitoringPoint.

HydroID	**Cerc**	**10% viable after 400m**	**'x' snails over '40' points**	**How many die every 10m?**	**% of total die every 10m**	**Distance from 'Origin'**
119	9.17	0.92	8.25	0.21	0.0225	0
118	9.17	0.92	8.25	0.21	0.0225	10
117	4.58	0.46	4.13	0.10	0.0225	20
116	9.17	0.92	8.25	0.21	0.0225	30
115	9.17	0.92	8.25	0.21	0.0225	40
114	4.58	0.46	4.13	0.10	0.0225	50
113	32.09	3.21	28.88	0.72	0.0225	60
112	9.17	0.92	8.25	0.21	0.0225	70

Table 2. The HydroIDs are assigned to specific MonitoringPoints (119-112 are located between HydroJunctions 1667-1552). Cercaria (Cerc) values, taken from data calculated in the larger database associated with Table 1, give the cercarial concentrations expected at individual each MonitoringPoint.

HydroID	119 *Passed*	118 *Passed*	117 *Passed*	116 *Passed*	115 *Passed*	114 *Passed*	113 *Passed*	112 *Passed*
119	9.17							
118	**8.96**	**9.17**						
117	8.76	8.96	4.58					
116	8.55	8.76	4.48	9.17				
115	8.34	8.55	4.38	8.96	9.17			
114	8.14	8.34	4.28	8.76	8.96	4.58		
113	7.93	8.14	4.17	8.55	8.76	4.48	32.09	
112	7.73	7.93	4.07	8.34	8.55	4.38	31.37	9.17

Table 3. Cercarial concentrations passed down from each MonitoringPoint to the next. MonitoringPoint 119 has an original concentration (i.e. - before receiving upstream inflow) of 9.17. By the time this original concentration travels the 10m to MonitoringPoint 118, 0.21 (See Table 2) will have undergone decay, leaving 8.96 to add to the original concentration at MonitoringPoint 118.

HydroID	119 *Received*	118 *Received*	117 *Received*	116 *Received*	115 *Received*	114 *Received*	113 *Received*	112 *Received*
119	9.17							
118		**18.13**						
117			22.30					
116				30.96				
115					39.41			
114						43.06		
113							74.12	
112								81.54

Table 4. Cercarial concentrations received by each MonitoringPoint, given upstream inflow. MonitoringPoint 119 has no upstream concentrations, so it remains the original concentration. MonitoringPoint 118 sums up its own concentration and the passed concentration from MonitoringPoint 119 (see Table 3).

HydroJunction	Accumulation: ACTUAL	Accumulation: NORMAL
1518	2425.66	1047.85
1536	2426.56	837.61
1537	987.18	426.49
1546	358.80	501.17
1547	182.53	382.69
1548	145.66	162.23
1549	261.94	288.60
1550	8.96	53.81
1551	216.96	232.53
1552	400.21	420.84
1553	4.58	18.35
1554	312.29	410.97
1555	521.25	709.98
1556	306.03	440.04
1557	581.09	475.13
1558	206.31	795.36
1559	251.16	387.84
1560	287.68	306.82
1562	449.49	541.41
1565	277.36	374.38
1566	9.17	18.35
1567	287.19	367.14
1568	406.02	674.49
1569	727.48	1000.89
1570	345.04	377.95
1571	115.86	657.30
1572	748.70	1004.16
1573	316.64	530.22
1574	4.58	18.35
1575	271.86	250.34
1576	1035.67	393.56
1578	527.22	622.75
1579	241.92	178.55
1580	170.45	492.85
1581	448.07	327.78
1582	108.60	234.30
1583	553.09	624.42
1584	9.17	18.35
1585	325.54	413.79
1586	32.09	18.35
1587	463.46	463.13
1588	539.68	495.55
1589	126.32	250.91
1590	606.11	493.76
1592	123.75	536.31
1594	477.71	384.60

1595	313.25	284.03
1597	170.82	339.90
1598	156.27	185.18
1599	212.87	392.28
1600	365.02	532.13
1602	0.00	18.35
1603	40.69	40.69
1604	393.65	412.45
1605	214.19	325.63
1606	247.55	281.75
1608	402.68	412.07
1611	146.14	393.88
1612	156.23	150.29
1613	18.34	18.35
1616	292.99	384.50
1617	104.05	172.46
1618	526.95	673.82
1620	4.58	18.35
1621	136.09	125.05
1622	4.58	18.35
1623	22.92	18.35
1625	0.00	18.35
1626	133.02	84.34
1627	777.53	363.13
1628	281.98	337.21
1630	109.07	219.33
1631	178.24	65.48
1632	98.13	99.38
1633	90.24	48.92
1634	195.20	202.76
1635	109.60	62.55
1636	401.21	287.53
1639	328.79	187.64
1640	125.84	145.66
1641	122.10	149.25
1642	161.18	318.54
1643	13.75	18.35
1644	38.00	61.84
1645	231.67	196.99
1646	170.99	95.27
1647	870.96	36.29
1648	50.99	53.61
1649	867.56	150.29
1650	511.60	311.11
1652	409.44	168.28
1653	49.40	36.29
1654	45.85	18.35
1655	0.00	0.00

1656	332.89	344.18
1658	194.26	261.56
1659	311.24	364.52
1662	84.52	179.14
1663	140.54	230.49
1664	117.19	189.46
1665	0.00	0.00
1667	0.00	0.00

Table 5. Cercarial Accumulations per HydroJunction. These values are taken from calculations in the larger spreadsheet version of Tables 2-4. Each HydroJunction is assigned a particular HydroID number. The Actual / Normal cercarial accumulations are then entered into the ArcHydro attribute table for the appropriate map. Missing HydroJunctions are due to negligible errors generated while connecting the ditch networks together.