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EVALUATION OF RECOVERY IN A POLLUTED CREEK AFTER INSTALLATION OF NEW SEWAGE TREATMENT PROCEDURES

by

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ABSTRACT

Response of Hickman Creek near Lexington, Kentucky to alleviation from serious sewage pollution was studied from January, 1973 through July, 1974. Wastes are now handled from an efficient secondary treatment facility and four sequential polishing lagoons before chlorination and discharge to West Hickman branch.

Physico-chemical tests gave no strong indication of residual pollution effects at the start of the study, approximately six months after the treatment facility opened. At low flow a slight oxygen sag, probably associated with algal growth in the lagoons, persists downstream from the outfall. Mean values for turbidity, nitrates and COD are somewhat higher at the outfall than at eleven stations within the basin. Orthophosphates are considerably higher in lagoon discharge than elsewhere in the system, which gains some phosphate from bedrock.

While the lagoons place some oxygen demand on West Hickman in the form of unicellular algal growth, they can and do receive surges of input that cannot be accomodated in the treatment plant. They would serve as a buffer to the stream in case of operational malfunction, which could overwhelm the small stream at low flow. The lagoons provide some benefits of tertiary treatment.

The diversity of benthic macroinvertebrates increased at most stations formerly affected by pollution but did not achieve the levels of two control stations on East Hickman Creek. Fishes reinvaded West Hickman more rapidly than did invertebrates but they also failed to achieve the diversity maintained at the control stations and observed in collections from 1960. Fecal and total coliforms 2 miles downstream from the lagoon outfall were as low or lower than elsewhere in the basin.

Changes within the basin were sometimes more clearly seen when stations were grouped by stream order. Urbanization of West Hickman may be causing physico-chemical and biological changes apart from the effects of or alleviation from sewage pollution.

The West Hickman Sewage Treatment Plant affords protection to Hickman Creek and produces a safe effluent that has allowed reestablishment of a variety of fishes, invertebrates and aesthetic qualities formerly associated with the stream. Presence of uncontaminated tributaries is thought to have sped observed recovery.

Descriptors: Water pollution*, Streams*, Sewage Lagoons, Invertebrates, Fish

Identifiers: Pollution recovery, Stream order

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Mr. John Moeller collected the coliform samples and performed the tests. His contribution is greatly appreciated.

Some data and observations on Hickman Creek during the summer of 1972 were obtained on a Biomedical Sciences Support Grant from the University of Kentucky.

The 1972 Limnology class gathered some information cited here and several other students at the University of Kentucky have helped in collecting fish and sorting invertebrate samples.

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INTRODUCTION

A decade-long trend toward worsening sewage pollution of Hickman Creek near Lexington, Kentucky was reversed in the summer of 1972 with the opening of a new secondary treatment plant backed with effluent polishing lagoons. The purpose of this investigation has been to determine the degree of stream recovery measured in terms of several physico-chemical parameters and by samples of the biotic community. These data furnish field evidence on the ability of such plant design and operation to maintain conditions suitable for aquatic life in a stream where the final effluent may at times be the principal source of flow.

Urban expansion into the upper basin of West Hickman Creek began in the 1950's and has accelerated due to the preferential growth of Lexington southward. By 1964 three small treatment facilities were operating near the head of the stream and the need for additional capacity was becoming evident. A small upstream facility, Lansdowne treatment plant, became encircled by private and commercial development and was closed in 1966, creating an immediate overload on the next unit, the Gainesway treatment plant with a rated capacity of 360,000 gpd. Bluegrass Disposal Plant, a third unit installed a West Hickman tributary has been expanded to 1.14 mgpd and is still operative. From early 1968 to January, 1971 the stream below the Gainesway outfall was a septic drain due to the bypass of as much as 600,000 gpd of untreated domestic wastes. The recovery zone extended well into adjacent Jessamine County. The lagoons and trunk line extension for new West Hickman Sewage Treatment Plant (hereafter WHP) located just inside Jessamine County were completed in January, 1972 and the lagoons received untreated and partially treated sewage until initiation of secondary treatment at WHP in late June, 1972. Upper West Hickman Creek in Fayette County began to recover from pollution effects but the entire main stem in Jessamine County was converted into a septic and recovery zone. The lagoons were heavily chlorinated to eliminate coliform bacteria; the first two were generally anaerobic and the last two periodically supported massive blooms of Euglena, Scenedesmus or Chlorella, which turned the creek bright green, but gradually died in its shaded waters. A detailed history of the situation emphasizing its social and legal implications is found in Miller and Wall (1974).

Current efficiency of secondary treatment at WHP is high. The plant routinely achieves 95% or better reduction of influent BOD on about 3.5 to 4 m.g.d., which is about half its rated capacity. Surges can be and have been bypassed to the first lagoon and there chlorinated. Coliform reductions are marked during lagoon transit. This and additional information can be found in Moeller (1975).

THE STUDY AREA

Hickman Creek, located in the Bluegrass region to the south and west of Lexington, is a tributary of the Kentucky River (Figure 1). The basin comprises approximately 97 square miles; maximum stream length measured from the source of West Hickman to the Kentucky River is approximately 36 miles. The West Hickman arm is 10.3 miles long; East Hickman is 10.4 miles long. The headwaters arise at elevations of about 1000'; within the study area stream gradient is about 13' per mile. Lower Hickman Creek downstream from Station 7 descends rapidly to enter the Kentucky River at normal pool elevation 514'. Upper valley profiles are gentle but those of the lower stream are very precipitous. The local mean temperature is 54.9°F and varies between a January mean of 33.1° and a July mean of 75.9°. Precipitation averages 46 inches annually, yielding approximately 17 inches per acre to stream flow. August, September and October are usually the months of minimal precipitation; drought reduces much of Hickman Creek to standing pools. The basin is underlain by locally phosphatic limestones with some exposures of shales. Except for urban development on the head of West Hickman, the basin is agricultural, supporting a large livestock industry. Row crops, such as corn and tobacco, occupy a smaller portion of the basin. Woodlands are mostly confined to stream banks and hilly lands near the river.

In recent years urban runoff and sewage effluent have combined to produce greater flow during all seasons in West

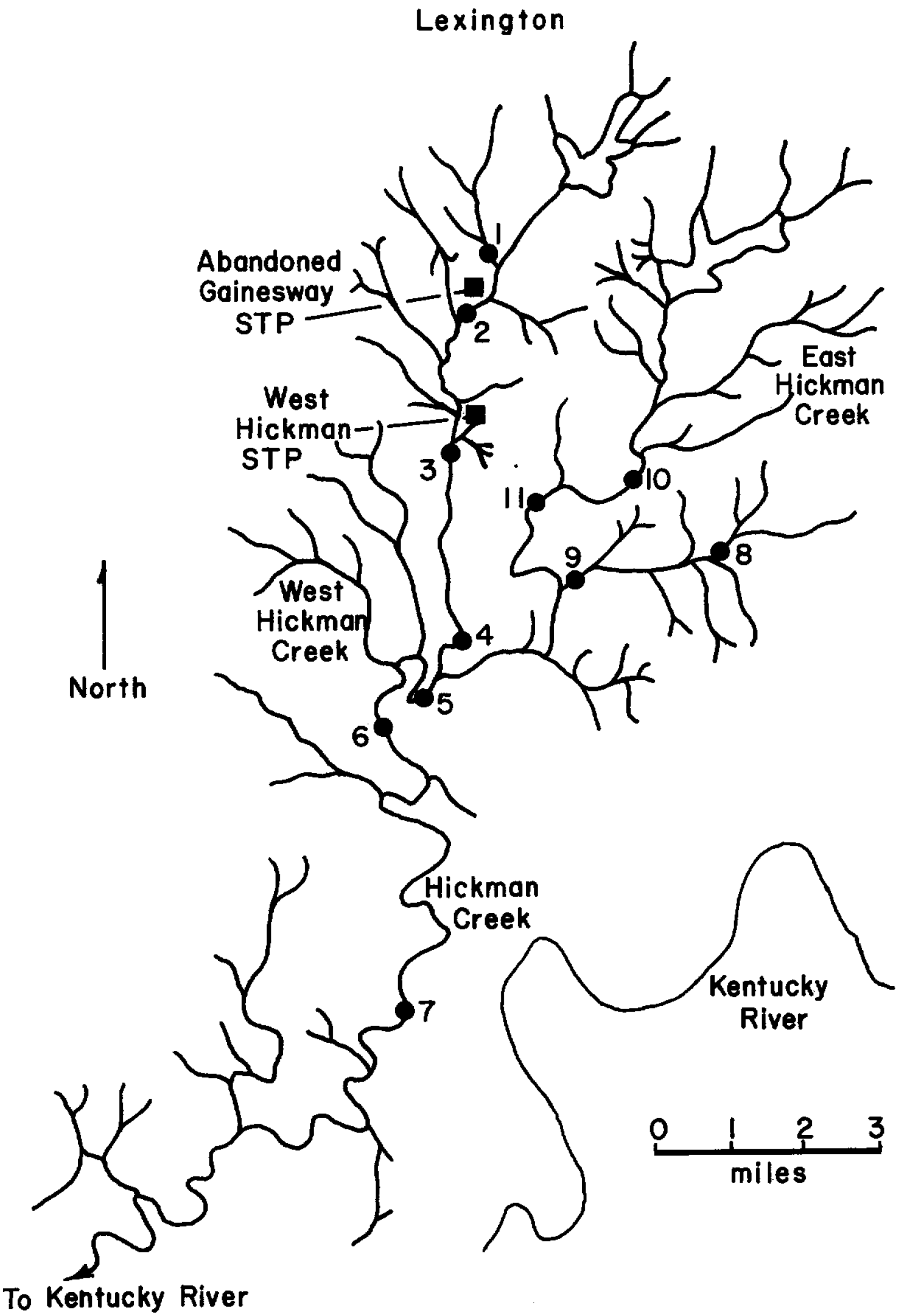

FIGURE I – MAP HICKMAN CREEK BASIN, KENTUCKY

Hickman than in East Hickman. Also the reservoir on the head of West Hickman is no longer used for municipal supply while that on upper East Hickman is utilized and overflows only after periods of heavy precipitation.

SELECTION OF STATIONS

Stations 1 through 7 constitute a linear sequence starting upstream and ending well downstream from the WHP. Four additional stations on East Hickman, chosen on the basis of similar stream orders, were sampled for comparative information. Thus, Station 8 (second order) is comparable to 1; Station 9 (third order) is comparable to 2, 3 and 4; Stations 10 and 11 (fourth order) are comparable to 5, 6 and 7. There is evidence to believe that local streams of like order should display similar physical, chemical and biological characteristics, if conditions in the watersheds are fairly homogeneous (Kuehne 1962). Sharp differences among such streams indicate a dissimilarity in one or more environmental conditions (Harrel and Dorris, 1968).

Within the constraints of stream order collecting sites were chosen near roads for quick coverage of the basin. During normal flow stage few pools were anywhere deeper than three feet and riffles were a foot or less in depth. Stations 4, 7, 8, 10 and 11 were well shaded while Stations 1 and 5 were totally exposed to the sun. Riffles at Stations 1 and 2 were noticeably impacted with silt from numerous sites cleared for construction, but Station 10 on East Hickman was similarly affected by local construction during the study.

METHODS

Physical, Chemical Data

Except for two periods when particularly adverse weather conditions interfered, physical and chemical data were taken monthly from January, 1973 through June, 1974. Stations 1 through 7 were visited sequentially between 10 AM and 1 PM and the remainder before 4 PM. Surface water samples were taken from the lower ends of pools. Temperature was recorded and Winkler oxygen samples (azide modification) were fixed in the field and all water samples transported in styrofoam chests. Discharge was measured at a riffle with fairly symmetrical cross section. Width was recorded and depth determined by taking the mean of 10 to 20 evenly spaced measurements across the riffle. Velocity was measured with a G&M propellor-type flow meter, which was moved slowly for three or four minutes across the bottom, midwater level and surface. The method was inaccurate any time that shallow water permitted the propeller blades to break the surface and at Station 5, where coarse rubble probably introduced errors into depth and velocity measurements.

Turbidity, orthophosphate and nitrate nitrogen were determined with a Hach DR-EL colorimeter as quickly as possible after return from the field. Oxygen titration and silver nitrate titration for chlorides followed procedures given in Standard Methods (1971). Chemical oxygen demand was determined by acid reflux with dilute potassium dichromate and silver sulfate catalyst. Samples were kept frozen until run. Selected physico-chemical tests were run on the lagoon effluent of WHP and included in tabular results under the heading, Station X.

Some data obtained in similar manner from Stations 2, 3, 4 and 6 during the summer of 1972 are used to illustrate some physical and chemical parameters before the WHP began to operate.

Biological Data

Invertebrate collections were made in the same sequence of stations as physical and chemical data but on a different day of the month to allow each set of data to be taken within a short time span. Macroinvertebrates were collected from riffles immediately downstream from pools used for water sampling. A one minute collection was taken in a Surber sampler following the technique described by Hynes (1961). Collections were preserved in 10% formalin for later sorting, counting and identification. Species, genus or rarely family designations were used, depending on the availability of suitable keys. A simple diversity index was used because taxa were not consistently identified to species level. The index used is:

$D = \frac{N-1}{lg_n\ I_t}$, where D is diversity, N is the total number of taxa, lg_n is natural logarithm and I_t the total number of individuals of all taxa in a sample. The arrangement of stations allows the biological findings to be compared as a linear sequence from Station 1 through Station 7 to observe downstream recovery. Alternatively, interbasin differences can be sought by comparing Stations 1 through 4 with Stations 8 through 11.

Fishes were collected on several occasions by electric shocker and seines. The material reported here was obtained over several days of collecting during May and June of 1974 and 1973 at all sites except Stations 5 and 10. Results are compared with a similar series from May and June of 1972 and a few earlier summer collections available from 1960. Identifications were to the species level.

Samples for coliform determinations were taken according to procedures recommended in Standard Methods (1971), including addition of sodium thiosulfate. Fecal and total coliform bacteria counts were determined by the membrane filter technique outlined in the Millepore Corp. Manual A 302 (1973) from Stations 2, 4, 6, 7 and 11 on eight different occasions during the study. All glassware was autoclaved and disposable petri dishes were used with fresh media prepared from broth dehydrates. Autoclaved phosphate buffer was used in rinsing. Total coliform plates were incubated under high humidity conditions at 35° C and fecal coliforms were incubated in a water bath at 44.5° C. Colonies were counted under cool-white flourescent bulbs. When two or more dilutions were required, the plate yielding 20-80 colonies was accepted as the most probable density. When plate counts fell outside the 20-80 range, that with the highest number was recorded.

When methodolgy is known to be similar, a few physical, chemical and biological data from earlier years (before January, 1973) are presented to expand the time frame of the present study.

RESULTS

Physical Conditions

Discharge of Hickman Creek and tributaries is ordinarily small (Table 1), but did exceed 100 cfs at the three downstream stations on occasion. The record is approximately that of base flow, there being no attempt to get measurements during high water. The relationships of discharge estimates from Station 1 through Station 7 seem good except for Station 5, where coarse rock fill caused trouble in obtaining accurate measurement of depth.

Exceptional rainfall in summer and autumn prevented any study site from ceasing to flow during this study, but in some years all upstream stations might be expected to do so. The impact of sewage lagoon effluent on discharge at Station 3 is difficult to discern except in October, 1973.

The small contribution of East Hickman Creek to base flow of the system is quite evident. Stations 1 and 8 have similar-sized basins but summer and autumn flow of the latter is much smaller, probably due to higher transpiration by plant cover. The West Hickman Creek reservoir is no longer tapped for municipal supply but the East Hickman Creek reservoir is so used and thereby reduces the flow past Stations 10 and 11.

Floods could not be measured but these have become severe enough on West Hickman Creek to cause damage to old bridges and to undermine and topple many trees along the streamside. Similar effects are not being noted on East Hickman.

Table 1. Discharge of Hickman Creek stations. Values expressed in cubic feet per second.

Date	Station No. 1	2	3	4	5	6	7	8	9	10	11
5-21-73	4.43	16.15	26.31	37.54	65.69	53.04	62.91	2.06	7.94	9.99	15.13
7-23-73	9.28	43.40	57.24	59.58	123.07	108.20	179.26	10.12	15.60	7.07	18.23
9- 1-73	1.15	3.52	6.31	10.13	14.56	14.33	15.93	0.59	0.37	1.74	1.05
10-12-73	1.02	1.35	5.77	6.74	7.66	8.68	9.56	0.16	0.22	0.68	0.96
11- 9-73	0.96	4.96	8.11	10.76	15.44	16.09	15.90	0.18	0.36	2.98	2.99
12-12-73	2.88	6.60	11.41	15.67	41.94	32.37	47.15	2.28	5.15	4.42	6.20
1- 8-74	5.59	18.63	27.27	38.11	95.12	113.94	110.63	10.54	13.47	8.11	18.00
2-11-74	3.03	11.93	21.97	24.01	54.47	57.75	63.77	1.88	8.90	10.74	11.20
3-27-74	4.39	10.99	33.04	40.76	53.44	81.61	99.25	9.14	8.39	15.00	15.51
5-26-74	1.74	16.23	21.08	17.34	25.83	32.03	30.88	0.25	0.52	0.60	3.28
7- 1-74	5.95	25.44	49.01	37.65	-	56.19	65.15	0.68	11.14	7.91	5.06

Table 2. Turbidity at Hickman Creek stations. Values expressed as Jackson Units.

Date	Station No. 1	2	X	3	4	5	6	7	8	9	10	11
1-12-73	4	23	19	9	14	13	5	4	18	27	10	11
3-13-73	5	10	22	2	10	7	2	2	1	2	10	22
4-17-73	75	3	10	3	5	5	5	1	1	3	5	2
5-21-73	12	15	12	12	25	18	22	12	2	18	40	5
6-23-73	2	7	23	8	16	25	12	14	7	10	7	8
7-23-73	60	50	10	35	40	40	30	30	50	20	60	35
9 -1-73	6	20	8	10	8	10	28	10	12	4	8	8
10-12-73	8	10	30	20	10	10	20	12	12	15	15	25
11- 9-73	8	10	35	25	18	20	22	18	20	20	22	25
12-12-73	5	5	8	6	6	6	4	4	6	4	5	6
1- 8-74	3	3	3	5	1	1	1	1	4	5	2	4
2-11-74	3	18	4	2	5	3	4	2	4	3	5	3
3-27-74	4	3	19	25	11	10	8	2	1	4	4	7
4-27-74	-	8	18	20	10	10		10	6	5	11	7
5-26-74	10	36	23	52	40	30	35	28	4	8	18	22
7- 1-74	30	70	25	20	37	22	29	43	11	18	36	20

The Hickman system is characterized by low turbidity at base flow (Table 2), never exceeding 75 Jackson units during this study. The highest reading resulted from children playing just upstream from the sampling area. Trucks crossing the stream above Station 10 twice resulted in rather high turbidity. Sewage lagoon effluent was sometimes green-tinged with algae but the turbidity values usually fell within the extremes recorded for a set of samples.

The total range of variability in surface temperature was 0-29°C (Table 3). The highest values were obtained in June and September, 1973 from the sewage lagoon outfall and Station 3 immediately downstream. However, these values do not appear to be more than 2°C above those obtained at other stations.

<u>Chemical Conditions</u>

Oxygen samples were collected during the best hours for photosynthesis and should represent nearly maximal values. Indeed, supersaturation was encountered commonly (Table 4). For example, the riffle at Station 1 was open to the sun and diatoms or filamentous algae often grew abundantly just upstream, creating ideal conditions for the frequent high oxygen values obtained. Neither the highest nor lowest oxygen tensions occurred in East Hickman Creek. Values were consistently high for the lagoon effluent; Station 3 compared favorably with other basin readings. However, a noticeable oxygen sag sometimes occurs below the lagoon discharge, as best shown in the data of May, 1974. Only one reading at Station 4 and one at Station 5 fall below 5 ppm. Considering the fact that untreated

Table 3. Surface water temperatures, (C°) at Hickman Creek stations.

Station #	1	2	X	3	4	5	6	7	8	9	10	11
Date 1/12	8	1	2	1	1	0	0	0	8	5	5	5
3/13	16	14.5	14.5	12	13	12	11	11	12	9	10	10
4/17	16.5	17	15	16	16	15	15	15	14	15	15	16
5/21	13.5	15	17	17	15.5	14.5	15	16.5	17	18.5	18	13.5
6/23	23	27	28	29	25	23	24	25.5	19	22	23	23
7/23	20	25	26	26	25	23	23	24	20	22	26	20
9/1	21	24	29	28	25	25	26	27	23	25	26	24
10/12	19	19	22	22	24	20	20	21	20	20	20	18
11/9	10	9	11	11	9	9	8	8	8	8	8	8
12/12	9	5	5	6	3	4	4	4	11	8	6	6.5
1/8	6	3	3	3	2.5	2.5	1	5	5	5	3	7
2/11	4	1	2	4	3	3	3	3	9	5	1	4
3/29	11	9	11	11	11	10.5	10.5	11.5	11	11	11	10
4/27	20	21	21	22	20	19	18	20	18	22	20	18
5/26	17	19	24	19	18	18	18	17	16	17	16	16
7/1	24	26	25	25.5	24	22	24	23.5	21	24	23.5	22

Table 4. Surface dissolved oxygen (ppm) at Hickman Creek stations.

Date		Station 1	2	X	3	4	5	6	7	8	9	10	11
1973	1-12	14.4	13.1	14.0	14.8	11.2	14.1	14.0	14.8	12.6	14.4	13.7	13.7
	3-13	14.4	16.6	13.4	14.2	12.8	11.8	12.3	11.7	13.0	14.7	13.0	11.7
	4-17	15.3	17.6	11.5	11.9	9.4	8.6	9.0	11.3	10.3	9.9	9.9	10.6
	5-21	13.9	13.2	13.3	13.1	11.4	10.2	12.3	15.2	12.2	14.4	11.3	13.3
	6-23	9.7	10.7	6.7	7.2	4.7	8.4	7.4	10.3	8.2	8.7	7.9	6.7
	7-23	8.6	7.6	7.4	8.4	8.0	6.8	8.0	8.2	7.8	8.2	6.8	7.4
	9-1	9.4	9.0	9.4	9.8	6.2	6.6	8.2	11.4	8.2	7.2	5.4	9.4
	10-12	17.4	9.6	8.8	7.8	8.4	5.6	7.8	10.0	8.6	7.0	5.0	8.8
	11-9	15.0	11.8	11.6	9.6	7.0	8.6	9.0	12.8	10.0	10.0	10.4	11.6
	12-12	11.2	13.0	11.2	11.0	12.0	11.8	11.6	12.8	11.0	9.6	12.2	11.2
1974	1-8	11.0	12.0	11.0	12.0	11.2	11.4	11.8	12.4	10.6	12.6	11.6	11.0
	2-11	13.5	13.4	13.4	11.4	11.2	11.8	11.8	12.4	12.4	12.4	12.6	13.4
	3-27	14.2	12.6	14.8	13.8	11.8	11.6	11.4	14.8	11.6	10.6	11.4	14.8
	4-27	12.0	12.2	11.2	11.8	6.8	8.0	9.2	10.8	8.0	6.4	9.2	11.2
	5-26	9.2	9.0	6.2	7.0	5.2	4.6	5.6	5.4	6.0	5.6	7.6	6.2
	7-1	8.0	7.0	10.6	7.4	6.8	6.2	6.4	7.9	6.8	5.7	7.0	10.6

lagoon waste was entering West Hickman Creek only six months before the start of this project, the change to highly aerobic conditions had already occurred by the first sampling period in 1973. Oxygen readings (ppm) taken in 1972 with the same procedures show the following:

	Station			
Date	2	3	4	6
6-13, 1972	5.4	3.9	--	2.5
7-11, 1972	7.8	6.1	2.0	4.8

These values, taken just before and just after the sewage treatment plant started operation show oxygen depression at Stations 3 and 6 in June, apparent response at Station 3 in July but a persistence of poor conditions at Stations 4 and 6.

Chemical oxygen demand was determined for all 16 sets of samples; these findings are summarized by station as minimum, maximum and mean in Table 5. For most stations the highest single value occurred in January, 1973. Broken fragments of the filamentous algae, Cladophora glomerata, were seen in many collecting bottles and probably contributed heavily to the COD. Lowest values were associated with summer and early autumn. Highest COD existed during late winter and spring in the lagoon effluent, which was far less variable than the streams. The tendency toward oxygen sag between Stations 3 and 6 is probably the expression of oxygen demand introduced by the lagoon effluent. The COD mean values are somewhat lower in East Hickman Creek, but are not much different from those of Stations 1 and 7.

At one or more times during the study most stations registered COD values much higher than the mean of the lagoon effluent. Thus, the WHP contribution to stream COD falls within the range normally experienced by the system.

Nitrate nitrogen levels are summarized in Table 5 in similar manner to COD. The maximum values for the lagoon effluent and Station 3 are the highest encountered but the mean level for these sites is but slightly out of line with other West Hickman stations. Values for East Hickman Creek are somewhat lower than West Hickman but the lowest nitrate nitrogen levels are recorded from the most downstream site, Station 7.

Orthophosphate levels from the lagoon effluent of WHP (Table 5) are within the range to be expected for secondary-treatment waste waters generally (Hopson, 1975). Lagoon retention does not in this case accomplish reduction of phosphorus as it apparently does for nitrogen, which suggests that in the Bluegrass region phosphorus is already naturally present in amounts greater than that required for the active growth of organisms. The gradual drop in orthophosphates from Station 3 through 7 appears to represent a passive dilution. Orthophosphates in East Hickman and in West Hickman above the sewage effluent are far lower and less variable than in the sequence of stations below the lagoon effluent.

During the study chlorides were not encountered in excessive amounts (Table 5). Two principal sources for chloride in the drainage system were noted. Street runoff produced high winter readings at Stations 1 and 2, and the lagoon effluent of WHP

Table 5. Chloride, orthophosphate, nitrate (all as ppm) and COD (mg/l) at Hickman Creek stations. Values for each station are maximum, minimum and mean of 16 samples taken on same days as in Table 4.

		Stations											
		1	2	X	3	4	5	6	7	8	9	10	11
Chlorides	Min.	4.0	4.0	10.0	4.0	3.0	2.0	2.0	1.0	1.0	1.0	2.0	1.0
	Max.	46.0	78.0	54.0	49.0	47.0	44.0	39.0	35.0	8.0	11.0	23.0	21.0
	Mean	21.0	18.4	28.6	23.2	20.8	16.9	15.6	13.4	4.2	4.8	7.8	7.8
Ortho-phosphate	Min.	0.9	0.2	4.6	1.8	3.0	1.9	1.5	0.7	0.5	0.5	0.4	0.5
	Max.	4.0	1.9	31.0	35.0	22.0	20.0	18.7	17.0	8.2	2.0	1.6	8.6
	Mean	2.1	0.9	10.8	8.9	7.9	6.5	6.0	5.1	1.6	1.0	0.8	2.0
Nitrate	Min.	1.0	0.5	10.5	0.5	0.5	0.5	0.5	0.3	0.3	1.0	0.8	0.3
	Max.	12.0	10.0	14.0	14.0	13.0	12.0	10.0	4.0	9.0	9.0	5.0	10.0
	Mean	4.2	2.8	4.9	4.2	3.6	4.1	3.3	2.5	2.9	3.2	2.6	2.8
COD	Min.	0.1	0.8	10.4	6.8	0.8	3.7	2.6	0.1	0.1	0.4	0.1	0.1
	Max.	60.4	82.8	80.3	24.2	49.2	71.0	54.4	42.0	41.0	25.8	68.8	79.2
	Mean	8.7	10.7	25.8	13.7	14.6	13.6	11.1	8.9	5.9	5.7	8.3	7.9

consistently was chloride-rich. The steady dilution of chlorides from the lagoon effluent downstream is similar to the pattern for orthophosphates. Values characteristic for East Hickman Creek are sharply lower than those of West Hickman Creek. Under certain conditions chlorides may provide a handy means of estimating downstream dilution of treated effluent.

Biological Conditions

Fecal and total coliform counts at Station 4, located two miles downstream from the WHP outfall, were generally lower than those recorded at Station 2, located just over three miles upstream in an area where a few septic fields still operate (Table 6). Results at Station 4 also compare favorably with coliform counts taken elsewhere in the Hickman basin. While the coliform data at hand are few and infrequently taken, they give no reason to believe that the WHP effluent degrades conditions within the basin.

Suitability of the various Hickman Creek stations for sustaining a diversity of macroinvertebrates is summarized in Table 7, in which stations are grouped by stream order. Third order sites on West Hickman Creek, Stations 2, 3 and 4, all show a trend toward greater number of taxa and increased diversity indices from 1973 through 1974. The gradual reappear- of snails, clams and mayflies probably accounts for the increased number of forms per collection. During several collections made at Station 2 in the spring of 1969, when the now abandoned Gainesway plant was operating upstream, only two taxa (red chronomid larvae and sewage sludge worms) could

Table 6. Fecal and total coliform density at selected station on Hickman Creek. Fecal counts given above and total counts below, both in organisms per 100 ml.

Date	2	4	6	7	11
1973	-	381	485	415	-
9-19	-	-	-	-	-
	1070	130	180	22	18
11-14	2600	480	950	430	480
1974	70	30	55	54	108
1-8	575	70	340	410	320
	76	2	28	39	50
2-27	255	36	160	83	196
	5300	1230	-	-	-
3-11	-	-	-	-	-
	250	540	940	1720	740
4-9	320	1500	3040	2000	2800
	10	10	105	10	120
4-25	240	380	680	310	560
	-	-	-	-	-
6-13	1900	400	2000	500	700

be taken at this site. The change at Station 3 is likewise impressive, there being 12 taxa per collection in 1974 compared with a total list of only 7 taxa obtained during the spring of 1972, when the WHP lagoons were functioning as settling basins for untreated wastes. However, it seems that Stations 3 and 4 have failed to recover to the extent that Station 2 has. None in this series of stations has reached the high and consistent diversity displayed by Station 9 on East Hickman Creek.

Not since the mid 1960's has there been any sewage treatment facility above Station 1 but urban growth and channel modification have occurred. There has been a decrease in number of taxa taken per collection and in the diversity index during this study, apparently due to the gradual disappearance of snails, clams, mayflies and crayfish. The mean of the 1974 diversity index and the average number of taxa per collection was less than half that for the East Hickman station of comparable stream order, which like Station 9 remained rather consistent during the study.

The fourth order sites below the junction of West Hickman Creek, Stations 5, 6 and 7, compare favorably with the fourth order sites on East Hickman, Stations 10 and 11. There are some changes that may represent trends, although the study period is too brief to say absolutely. In the spring of 1972 only 14 taxa were collected in four visits to Station 6. Thus, the average number of taxa per collection in 1973 (15.3)

Table 7. Diversity indices and average number of taxa per collection for Hickman Creek invertebrate samples grouped by stream order.

Coll. Date	Collection Sites: Second Order 1	8	Third Order 2	3	4	9	Fourth Order 5	6	7	10	11
1973 1-15	1.39	2.90	1.88	1.44	1.80	3.16	3.30	2.71	2.33	2.98	2.70
2-18	1.28	2.88	1.94	1.39	1.55	3.17	2.25	2.42	3.00	2.67	2.34
5-6	1.18	2.32	2.18	1.18	1.31	2.50	2.40	2.56	2.28	2.27	2.16
7-6	1.17	2.62	2.25	1.94	1.90	2.66	2.46	2.03	2.40	2.64	1.67
9-22	2.26	2.71	1.90	1.29	1.59	2.84	2.15	1.97	2.75	2.28	1.51
12-7	1.18	2.38	2.24	1.38	2.13	2.71	1.93	3.43	4.27	2.91	3.09
1974 2-1	1.10	2.28	2.72	1.85	2.31	2.78	2.43	3.02	2.65	3.13	2.49
4-15	1.03	2.88	2.72	1.54	1.83	2.73	2.47	2.18	3.45	3.08	3.14
6-19	1.43	2.31	1.86	1.79	1.79	2.53	1.71	2.22	2.38	2.47	2.79
Average taxa/coll. 1973	10.5	17.3	13.5	10.7	11.7	18.7	13.2	15.3	17.8	17.2	15.3
Average diversity 1973	1.41	2.64	2.07	1.44	1.66	2.84	2.42	2.54	2.84	2.63	2.25
Average taxa/coll. 1974	8.0	17.0	16.3	17.3	14.0	18.3	12.7	15.7	18.7	19.0	18.7
Average diversity 1974	1.19	2.49	2.43	1.73	1.98	2.68	2.20	2.47	2.83	2.84	2.81

and that for 1974 (15.7) suggest that the station continues to show recovery from an earlier depletion of invertebrates. While Station 7 maintains high average diversity - and the most diverse single collection obtained during the study - the situation is not the same at Station 5, which seems more to resemble Stations 3 and 4.

The fourth order East Hickman sites chosen for comparison, Stations 10 and 11, yield results similar to those obtained at Stations 6 and 7. Four collections at Station 11 made in the spring of 1972 yielded 14.5 taxa per collection compared with 15.3 taxa per collection in 1973 and 18.7 in 1974. Not until the study was nearly completed was it discovered that prior to 1971 this section of East Hickman experienced pollution difficulties from dairy barn wastes and disinfectants allowed to enter the creek about 0.2 miles above Station 10. This may account for the marked diversity increases recorded at Stations 10 and 11 during the study.

The number of fish species taken during the summers of 1973 and 1974 is presented in Table 7, along with collections taken by the author and students in 1960 and 1972 for comparison. Stations 5 and 10 were not sampled due to failure to obtain permission. Stations have been grouped by stream order. Stations 8 and 9 seem to be stable habitats on the basis of physico-chemical and invertebrate data gathered regularly during the study; they show some variability in the numbers of fish species, but it should be noted each year's estimate

Table 8. Number of fish species at Hickman Creek stations, arranged by stream order. Some data from earlier years; stations 5 and 10 omitted.

Station Number	1	8	2	3	4	9	6	7	11
Stream Order	II		III				IV		
Year									
1960	-	-	-	16	-	-	17	*22	-
1972	8	-	10	1	-	17	16	-	-
1973	6	10	8	11	6	13	15	17	18
1974	7	12	7	11	6	14	8	15	16

*4 miles downstream from Station 7.

is based on a single sample. Great importance can be ascribed only to large differences in number of fishes. A significant change has occurred at Station 3, where only one species was caught in 1972 before the WHP became functional and where 11 species have been taken in the two succeeding years. Re-invasion of this reach was rapid and it supported more species than any other station on West Hickman in 1973 and 1974. Of the fourth order sites Station 6 seems to be losing species while Stations 7 and 11 have shown little change. Station 8, second order, and Station 9, third order, sustain the best fish diversity for streams of their ordinal rank. Certain long term changes have occurred in the entire Hickman Creek basin. Collections taken in 1960 at or near three of the sites used in this study contained greater numbers of species. Notably smallmouth bass were taken then but not in collections made since 1972. Several types of minnows, darters and suckers that were then fairly common seem now to be rare and not likely to appear in a catch. These changes may be related in part to sewage pollution but can hardly be attributable entirely to that cause. Factors other than those addressed in this study must also be involved.

DISCUSSION

Oxygen and COD tests started on West Hickman Creek only six months after initiation of full sewage treatment at WHP failed to reflect any marked residual effects of pollution. High water during the late summer and autumn of 1972 was apparently effective in removing accumulated organic wastes. Odors long associated with septic conditions in the stream have not been detected during any of the many trips made throughout this study. Thus, the operation of WHP quickly set the stage for biological recovery.

A slight oxygen sag does occur below the WHP lagoon outfall at times of low flow. Algae washed from the lagoons may be a principal cause of this sag but is far from being the sole source of organic material contributed by the basin. Though not serious at present, discharge of increasing amounts of unicellular algae into the receiving stream could become a matter of concern. The WHP has the design capacity to bypass any of the four lagoons and this technique, perhaps along with chemical control, probably can avoid future problems. Algal control through fish stocking and harvesting is a possibility that would require additional study and experimentation to evaluate properly.

Organisms in the lagoons seem to metabolize much of the available nitrogen while allowing phosphorus to escape in large amounts. Thus, tertiary treatment benefits may exist for some, but not all, basic nutrients. Polishing lagoons in phosphorus-poor regions might perform better in removal of this nutrient than do the WHP lagoons.

An advantage of the polishing lagoons, which may become more critical as WHP reaches its rated capacity, is that surges received by the plant are bypassed to the lagoon system rather than to the stream. Thus, large amounts of potential oxygen demand are retained within the treatment system. This buffering capacity would be very beneficial should the plant suffer a malfunction, especially if it came during low stream flow. This advantage of lagoons is important in Lexington or any similar city that must discharge its wastewaters into very small streams.

Through the course of the study it was expected that faunal recovery at Stations 3, 4 and 5 would come to match that of Station 2, which is upstream from the lagoon effluent. This recovery did not develop so completely. The literature suggests that chloramines can be produced in toxic amounts by wastewater chlorination, especially when ammonia is present. Neither ammonia nor chloramines were tested in this study, but the possibility exists that the latter could have an inhibitory effect on Hickman Creek for some distance below the WHP outfall. Many invertebrates and fishes do survive in this part of the stream, so the problem cannot be viewed with alarm.

In present amounts chlorides introduces by the WHP or other domestic and agricultural practices constitute no problem. Serious effects of road salt on streams have been reported (Kunkle, 1972); one rather high winter reading at Station 2 indicates that road salt could become a future problem in West Hickman tributaries. Snowfall was exceptionally light both winters of this study, so only slight and infrequent salting was needed. Stream values well above the observed 78 ppm chloride might be expected in a severe winter.

Fecal and total coliform counts taken at Station 4 show that the area immediately below the WHP compares quite favorably with other sampling points in the Hickman basin. Although the stream seems safe from the public health standpoint, certification of Hickman Creek for contact recreation would require considerably improved control over several point and non-point sources of real or potential contamination. Nonetheless, aesthetic and recreational values have returned to West Hickman Creek with the disappearance of odors and the reestablishment of fishes, including some game forms.

The entire Hickman basin was observed to be in a state of flux with regards to benthic macroinvertebrates. Perhaps this is to be expected where so many shifts in environmental characteristics occur simultaneously. Favorable changes were expected and did develop on West Hickman Creek, except for Station 1, where channelization and urban construction are probably prime factors in the deterioration observed. Increases in diversity at Stations 6 and 7 suggests that they were well within the recovery zone before the WHP became functional. Surprisingly, Stations 10 and 11 also displayed increased diversity during the study and were later found to have had a pollution episode of their own. Invertebrate sampling thus can reveal pollution for some time after the event (Wilhm and Dorris, 1968), although it cannot give an accurate indication of the nature of the pollutant, as can direct physical and chemical analysis at the time of disturbance. Stations 8 and 9 served as yardsticks for the degree of improvement observed at other locations in the study area. It is impossible to say that these sites provide prime faunal conditions and retain all invertebrates that occur in the region, but they do display high diversity and stability through time. It is likely that they reflect optimal conditions for the basin as it exists today.

Fish have been little employed as biological indicators, though Tsai (1973) has used them to monitor water quality below sewage outfalls. The present study suggests that fishes in many ways are comparable to invertebrates as quality indicators and have the advantage of ease of identification at the species level. Also, much time in handling of collections is avoided. Still, invertebrate sampling probably tells more about specific habitat conditions and certain species may be sensitive to minor changes. Fishes are highly motile and cover large sections of a stream so long as passage is not totally precluded by adverse conditions.

Cairns, *et al* (1973) reviewed three cases of stream pollution and concluded that reinvasion and recovery were faster after abatement when healthy stream conditions persisted above the source of pollution and when tributaries harbored remnants of the fauna. Such conditions do exist in a short reach above Station 2 and in branches of East Hickman Creek. This may account for the rather quick response of the system to pollution abatement and speaks favorably for the protection of some elements of the watershed to provide future natural adaptability.

CONCLUSIONS

1. As measured by several physical, chemical and biological parameters, West Hickman Creek has recovered significantly from the effects of sewage contamination in years previous to July, 1972.

2. West Hickman Creek and the mainstem just below sometimes display a moderate oxygen sag.

3. Nitrate nitrogen is but slightly higher in WHP lagoon effluent than at other points in the stream basin.

4. Orthophosphates are higher in WHP lagoon effluent than elsewhere in the basin, and decrease gradually downstream as though by dilution. Local phosphatic rocks seem already to provide this nutrient in ample amounts for biological activity.

5. Chloride levels are lowest in East Hickman Creek, highest in West Hickman and intermediate in the mainstem. In the future road salt might produce damaging effects on organisms in upper West Hickman but there is no evidence that such is presently the case.

6. Lagoons at WHP can receive influent surges and thus buffer the stream. They also provide a margin of safety should a plant malfunction occur. However, unicellular algae washed from the lagoons into the creek may on death generate oxygen demand associated with the sag noted above.

7. Base flow of West Hickman Creek is greater than that

of East Hickman. Observation indicates that floods are more frequent and severe on West Hickman, a situation that may cause future faunal change apart from other aspects of water quality.

8. Macroinvertebrate diversity increased along West Hickman Creek during the study, except for the upstream and most urbanized station. Diversity declined slightly at one station on the lower mainstem but increased notably at two others. This suggests that the effects of sewage pollution extended far below the West Hickman branch. Diversity increases at two points on East Hickman Creek seem to be the result of a local case of pollution. High diversity and consistency characterized Stations 8 and 9 in a highly rural setting.

9. Especially at Station 3, the reestablishment of certain fishes was rapid in the formerly polluted section of West Hickman Creek. Fish diversity information seems to complement that on invertebrates. Long term trends for fish indicate that some species may no longer survive in the basin.

10. The rapidity and extent of faunal recovery in West Hickman Creek is probably associated with the fact that some undisturbed habitat persisted above the point of sewage pollution as well as in parts of East Hickman Creek.

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