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PHOSPHORUS LOSS AT SEWAGE WORKS IN THE LOUGH ERNE REGION

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ABSTRACT

Incidental loss of phosphorus (P) in sewage disposal works (SDWs) in the Lough Erne study area is examined through a review of the literature, consideration of operating data from U.K. SDWs and consultation with SDW Managers in Northern Ireland.

The number, type and size of SDWs in the region is portrayed cartographically and a summary of each sewage treatment process provided.

The literature and SDW operating data show a wide range of P loss between different treatment processes and between different SDWs of the same type. Northern Ireland figures for P loss appear somewhat lower than those observed elsewhere, varying between 5% and 20% depending on the type of SDW.

1. INTRODUCTION

The progressive eutrophication of Lough Erne Ireland (Fig. 1), in the period since the early 1950s, is hypothesised to stem largely from the increased loading of phosphorus (P) from sewage inputs. The sharp upward turn in lake productivity documented by Battarbee (1977) coincides with the widespread conversion from 'dry' to 'water borne' sanitary systems in the catchment.

It is proposed that prior to the 1950s much of the P in domestic sewage did not reach the surface waters of the catchment as sewage was disposed of on land, and subsequently bound within the soil, or was lost within the 'sewerage systems'[1] owing to old and poorly maintained sewers. However, with the construction and extension of modern hydraulically designed sewerage systems in towns and villages, P in sewage was channelled via sewage disposal works (SDWs), directly to water courses and the lake.

This hypothesis is being examined in an S.S.R.C. sponsored research project which seeks to determine the magnitude and importance of changing P inputs from sanitary systems to Lough Erne since 1850. Three previous papers in this series have examined the impact of changing demography and diet on P output (Patrick and Battarbee 1981), the significance of septic tank systems (Patrick and Battarbee 1982), and the contribution of detergent P within the catchment (Patrick 1983). Whereas these papers concentrated on factors influencing the supply of P to water courses, this paper seeks to document the extent to which P is removed from sewage in SDWs and is thus unavailable to surface waters.

SDW construction occurred late in the Lough Erne region (see Table 1) compared to other areas of the British Isles. In 1951 only five small and

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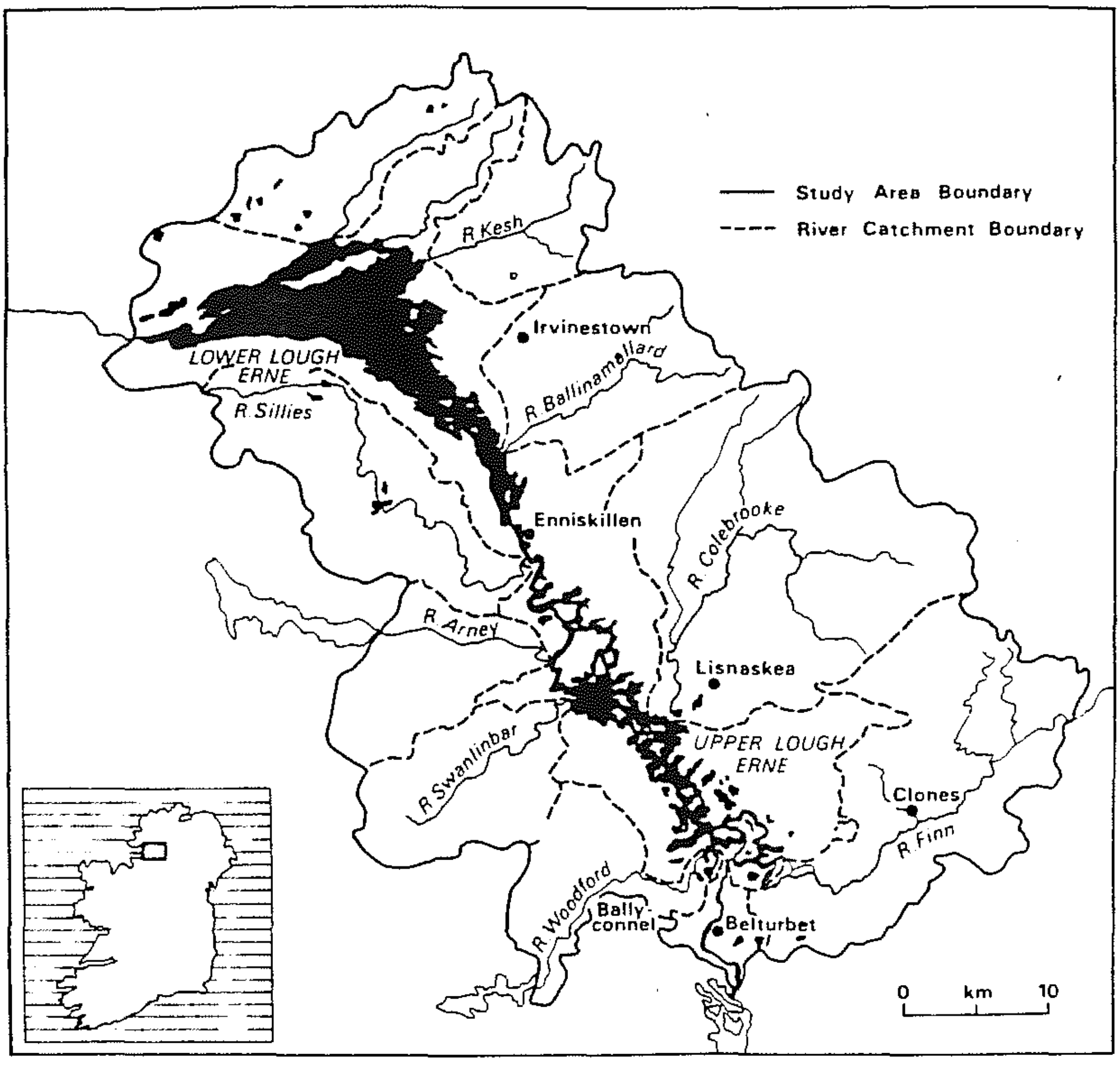
[1] Before the installation of modern sewerage schemes many sewers were crudely designed and intended only for surface water.

inefficient SDWs existed in the study area (Fig. 3). Since then they have been built either as part of new sewerage schemes or as an addition and required improvement to an existing sewerage system. In size they vary from small septic tanks and filters serving two or three council houses, to large activated sludge plants such as that at Enniskillen serving 2863 households (1976) (Figs. 4-5).

Consideration of P retention at SDWs is essential in any attempt to ascertain the output of P from sewage to a water body, particularly where documentary rather than experimental methods are employed. A large body of literature exists concerning the requirement and techniques for P removal at SDWs in tertiary treatment processes, but few studies exist that are specifically concerned with the 'incidental' reduction of P in the normal primary and secondary sewage treatment processes. Studies that take no account of P loss at SDWs (e.g. Wood and Gibson 1973), or assume that sewage treatment has little effect on P levels (e.g. Finstein and Hunter 1967, Bouldin et al 1975), will almost certainly over-estimate the contribution of sewage P. Similarly, studies that rely on a general assumption (e.g. see App. 1) of P reduction without considering the type and efficiency of processes involved, are also likely to incorrectly assess P outputs.

FIG.1. THE LOUGH ERNE STUDY AREA



2. SEWAGE TREATMENT PROCESSES

To estimate P loss, an understanding of different sewage treatment processes is necessary. Schaffner and Oglesby (1978) recognise that since some P is removed by each major operational unit in SDWs, the type of treatment afforded to wastes must be considered in accounting for P outputs. Whereas no two sewages are alike, processes in all SDWs fall more or less into a general pattern which Bolton and Klein (1971) summarise as follows:

1. Removal and/or disintegration of gross solid matter
2. Removal of grit
3. Separation and treatment of storm sewage
4. Removal of suspended solids
5. Aerobic biological treatment
6. Removal of suspended solids from biologically oxidised sewage.
7. Final improvement of effluent
8. Sludge treatment and disposal

The following section presents a summary of the processes involved in the types of SDW found within the study area.

2.1 Primary Sedimentation

In 1976 only two SDWs in the region employed primary sedimentation as the sole form of treatment, at Belturbet and Newbliss in County Cavan (see Fig. 4). At Ballyconnell, also in Cavan, sewage is temporarily retained in pump sumps before direct discharge to the river.

However, sedimentation is employed as a primary treatment process in most other types of SDW. By providing a period of quiescence in a basin, suspended solid matter is allowed to settle by gravity decreasing the strength of the sewage and making it more amenable to biological oxidation. Primary sludge is withdrawn from the basin at frequent intervals to prevent the onset of anaerobic biological action (Bolton and Klein 1971).

2.2 Percolating (Trickling) Filters

Nineteen SDWs of this type were installed in the region between 1952 and 1976, serving medium size populations between 9 and 610 households in 1976 (see Figs 4, 5). In its simplest form, a fixed bed of rock or synthetic media is dosed by primary effluent from a distributing system, commonly a rotary arm. The organic material in the wastewater is degraded by a population of micro-organisms attached to the filter media (Fig. 6).

Schematic Description of Percolating Filter Process
(After Vernick and Walker 1980)

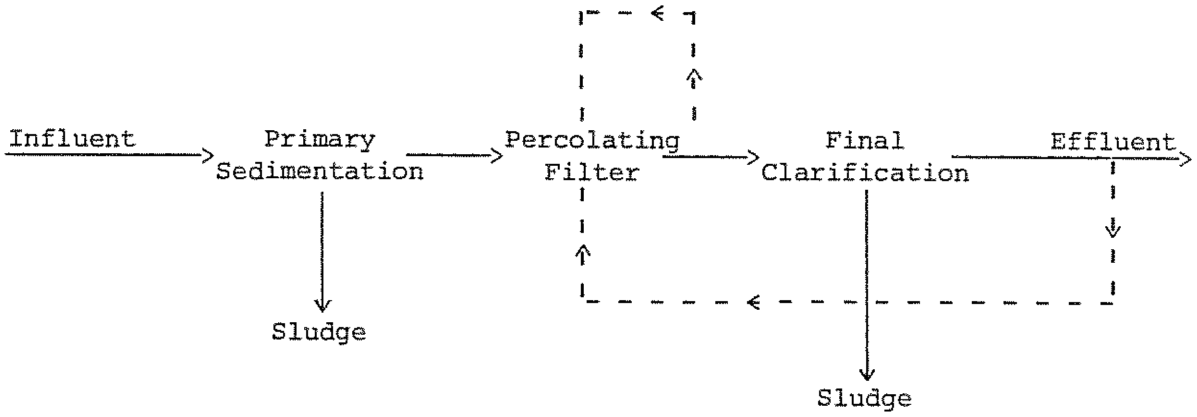


FIG. 6

2.3 Activated Sludge

Three such SDWs exist in the study area: at Enniskillen (installed 1973, serving 2863 households in 1976), Lisnaskea (installed 1974, serving 482 households in 1976), and Irvinestown (installed 1972, serving 388 households in 1976) (see Figs. 4, 5).

In principle activated sludge plants operate by admitting sewage, adding some activated sludge, and aerating the mixture for a suitable period (Mann 1979). In the presence of oxygen micro-organisms oxidise the soluble and colloidal organic material to Co2 and H_2O. Successful treatment depends on the correct combination of organic matter, activated sludge, air and time. The mixture of micro-organisms and wastewater formed in the aeration basin - the 'mixed liquor', is transferred to gravity clarifiers for liquid - solids separation. A measured proportion of the sludge deposited is returned to the aeration basin to treat further incoming sewage (Fig. 7).

Three broad types of activated sludge plant are characterised by the period of aeration during which sewage and activated sludge are in contact: 'high rate', 'conventional' and 'extended' aeration. The type of plant required depends on the organic loading to be treated (Vernick and Walker 1980). Conventional plants receiving moderate to high organic loads commonly employ an aeration period of between four and eight hours.

All three activated sludge plants in the study area are of the conventional form, but each exhibits a variation of the basic process: Enniskillen - surface aeration, Lisnaskea - two stage fine bubble aeration, and Irvinestown - coarse bubble aeration.

Schematic Description of the Activated Sludge Process
(After Vernick and Walker 1980)

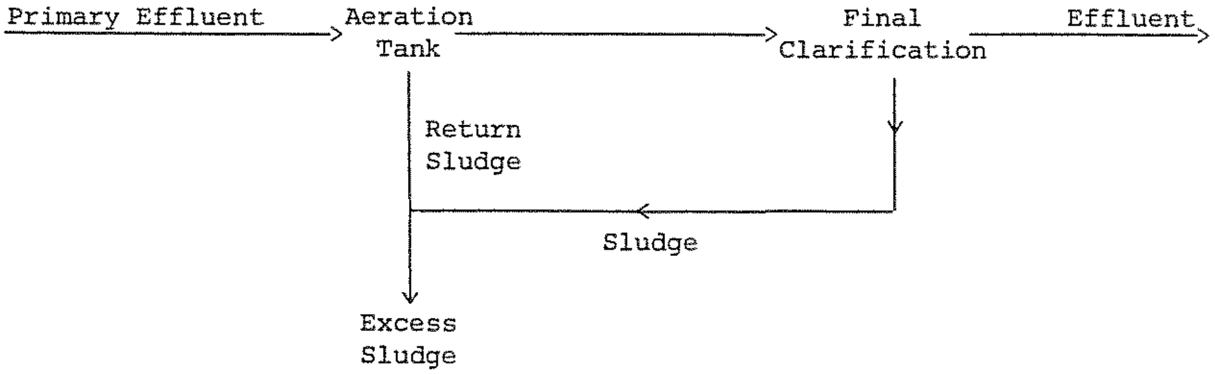


FIG. 7

2.4 Extended Aeration

This process, a variation of the conventional activated sludge process, is commonly available in package form suitable for small communities discharging a low BOD load. Eleven SDWs of this type serving populations between 10 and 117 households, existed in the study region in 1976 (see Figs. 4, 5).

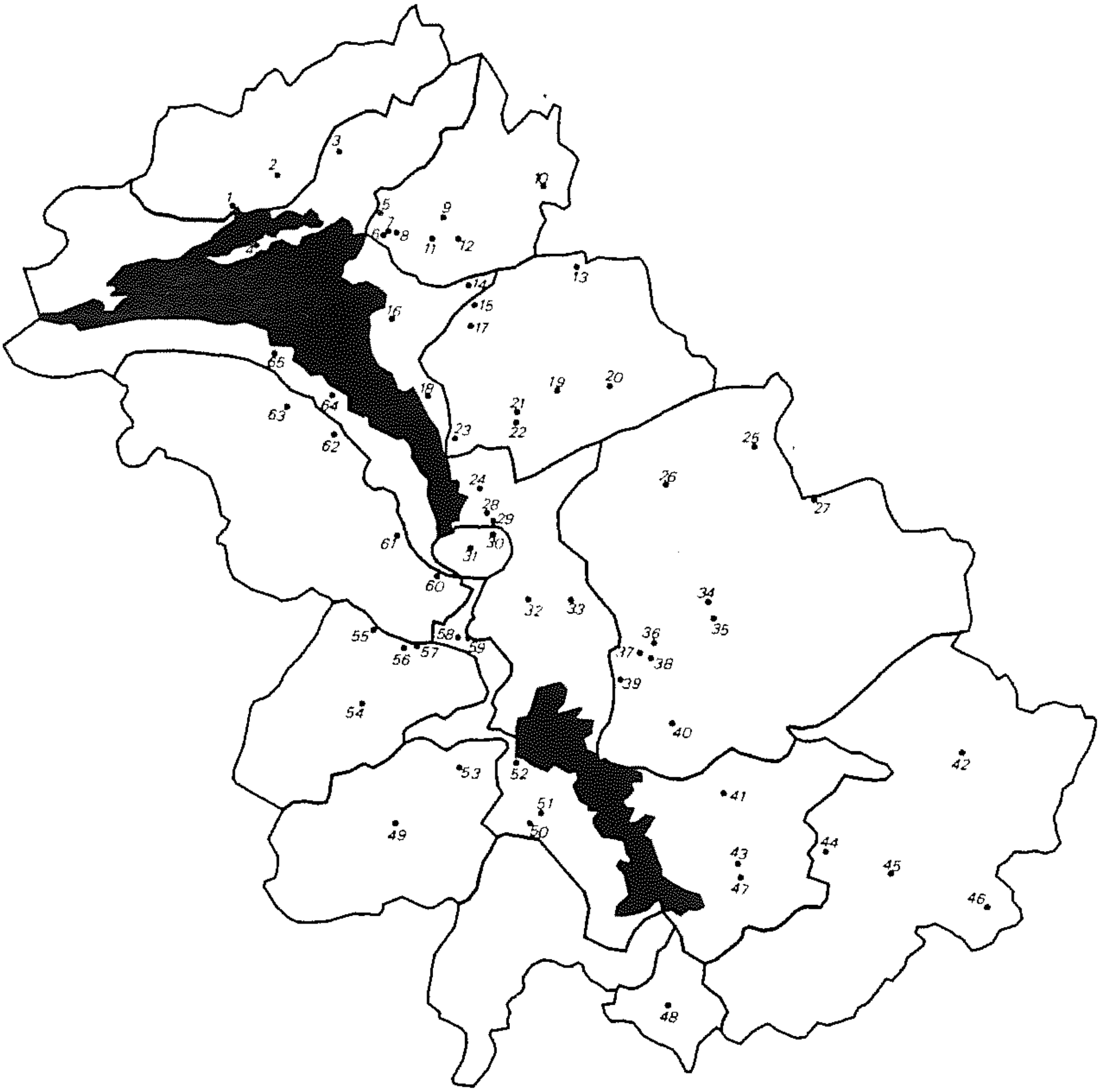
As primary sedimentation can be eliminated, the need to discharge a primary sludge is removed. The contact time between sewage and sludge is much longer than in the conventional process, often in excess of 24 hours, this can have important consequences for P removal (see pages 15, 16). During the period of aeration the processes of absorbtion, assimilation, growth and partial aerobic digestion take place concurrently (Mann 1979).

2.5 Septic/Sedimentation Tank and Filter

Small housing sites in the study area, sometimes comprising only two households, are served by small SDWs of this type. Primary settlement and partial anaerobic treatment (in septic tanks) occurs in the tanks before the effluent is aerated through a small filter. Where sedimentation, as opposed to septic tanks, are utilised, the process is an exact microcosm of that in larger percolating filters. Thirty such SDWs existed in the study area in 1976, serving between 2 and 41 households (see Figs. 4, 5).

All SDWs produce quantities of waste sludge at one or more stages of the treatment process. As all P removed from the wastewater is incorporated into the sludge, the treatment and disposal of the material can form a major influence on the overall loss of P within the SDW system. This influence is described and the implications are related to the study area in the discussion on pages 17-18 and 24-25.

Fig.2 LOCATION OF SDWS (AS OF 1976)



For key see Table 1

TABLE 1. KEY TO LOCATION, TYPE, AGE AND SIZE OF SDWs IN THE STUDY AREA

SDW No. From Fig. 2	Location	Type[1]	Date First SDW Installed[2]	Equivalent Pop. Served (Persons 1974)[3]	Design Pop. (Persons)[4]
1	Letter	STF	C1965	8	
2	Pettigoe[6]	PF	1975		
3	Drumgowna West	STF	C1965	8	
4	Mullans	STF	C1965	8	
5	Letterkeen	STF	C1957	16	
6	Rosscolban	STF	C1965	8	
7	Kesh	PF	1965	668	550
8	Mantlin	STF	1958	16	
9	Ederny	PF	1964	535	400
10	Lack	PF	1964	243	200
11	Ardess	PF	1970	55	115
12	Carn	STF	1958	16	
13	Tummery[5]	STF	1968	C40	
14	Drumbulkin	STF	C1965	8	
15	Drumharvey	STF	1959	40	
16	Lisnarrick	EA	1966	138	250
17	Irvinestown	AS	1972	1956	2250
18	Killadeas	EA	1965	40	50
19	Kilskeery[5]	STF	1952	C55	
20	Trillick[5]	PF	1957	C390	
21	Ballinamallard A.	PF	1960	577	500
22	Ballinamallard B.	EA	C1948	319	300
23	Ballycassidy	EA	1974	68	200
24	Trory	PF	1963	132	163
25	Clabby	PF	1959	200	190
26	Tempo	PF	1959	566	300
27	Fivemiletown	PF	1954	1274	707
28	Drumgay	STF	C1970	88	
29	Woaghternerry	STF	1963	56	
30	Killyvilly	STF	1958	80	
31	Enniskillen	AS	1973	13831	15000
32	Tamlaght	PF	1963	346	180
33	Lisbellaw	PF	1935	890	934
34	Monmurry	STF	C1970	8	
35	Brookeborough	PF	1956	807	440
36	Maguiresbridge	PF	1961	727	500
37	Drumgoon	STF	C1970	24	
38	Aghnaskew	STF	C1970	16	
39	Drummack	STF	1975		
40	Lisnaskea	AS	1974	2374	2000
41	Donagh	EA	1970	270	341
42	Rosslea	PF	C1946	397	500
43	Newtownbutler	PF	1956	936	822
44	Magheraveely	EA	1973	94	145
45	Clones[6]	PF	C1906	C2500	
46	Newbliss[6]	PS	1963	?	
47	Kilgarret	STF	C1970	16	
48	Belturbet	PS	1965	C1200	

TABLE 1. cont.

SDW No. From Fig. 2	Location	Type[1]	Date First SDW Installed[2]	Equivalent Pop. Served (Persons 1974)[3]	Design Pop. (Persons)[4]
49	Swanlinbar[6]	PF	C1965	C300	
50	Derrylin	EA	1971	322	600
51	Coragh	STF	1973	24	
52	Aghakillymaud	STF	1974	20	
53	Kinawley	PF	C1937	144	200
54	Drumlaghy	PF	1953	167	240
55	Letterbreen	PF	C1963	32	15
56	Derryaghna	ST	1954	32	55
57	Skea	EA	1953	44	120
58	Bellanaleck	PF	C1960	140	312
59	Killywillan	STF	1957	40	
60	Drumgallon and Drumawill	EA	1956	213	375
61	Springfield	EA	C1960	80	130
62	Monea	STF	1953	36	
63	Derrygonnelly	EA	1965	1086	1250
64	Blaney	STF	1963	8	
65	Churchill	PF	1970	57	65

[1] AS = Activated Sludge
EA = Extended Aeration
PF = Percolating Filter
PD = Primary Sedimentation
STF = Sedimentation or septic tank and filter

[2] Not necessarily the existing SDW

[3] From D.O.E. (1974). Includes trade effluent and <u>all</u> connected premises

[4] From D.O.E. (1974)

[5] Located in Co. Tyrone - data provided by D.O.E. in Omagh

[6] Located in Republic of Ireland - data from miscellaneous sources.

Fig. 3 LOCATION AND TYPE OF SDWS 1951

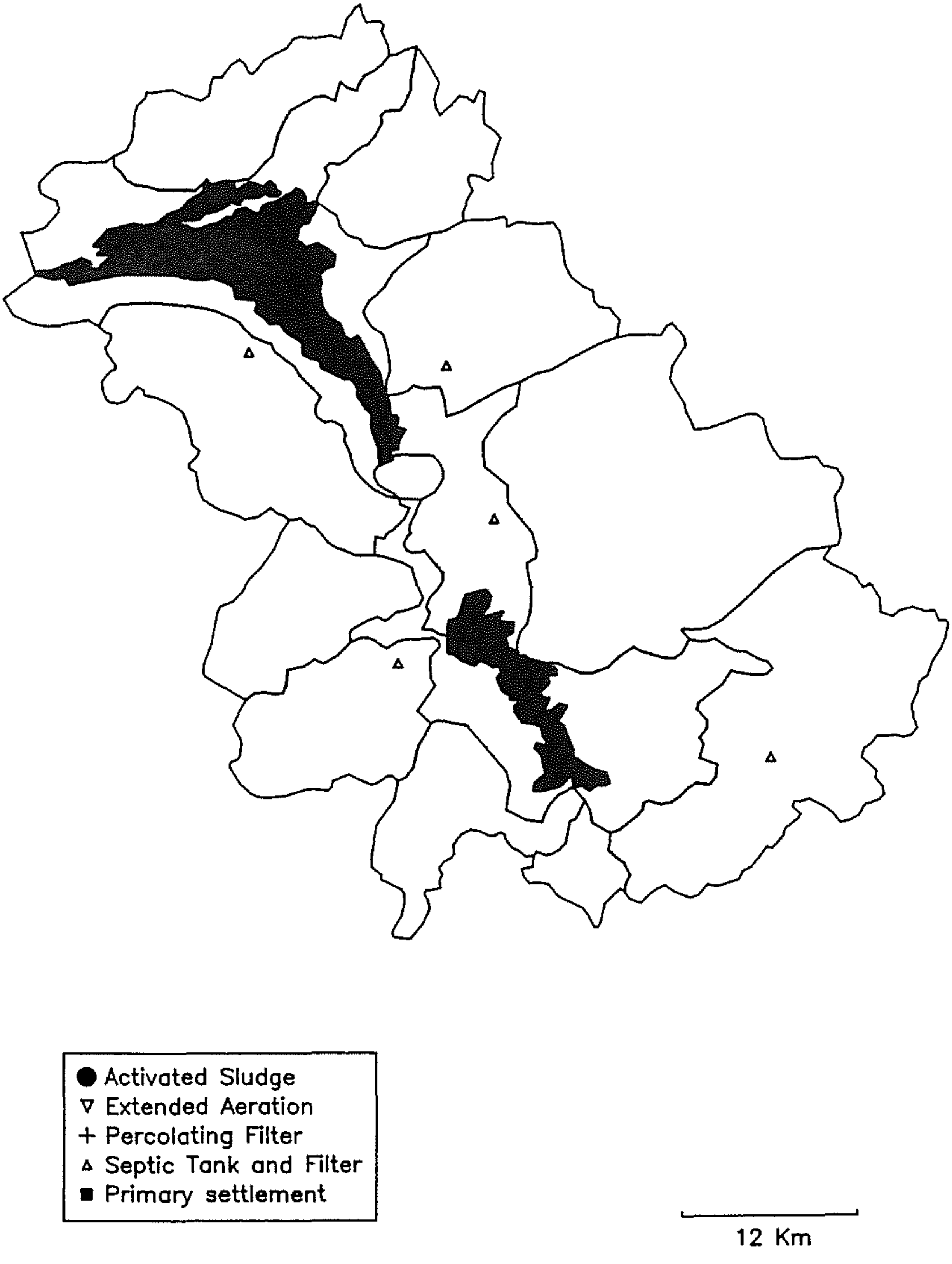


Fig. 4 LOCATION AND TYPE OF SDWS 1976

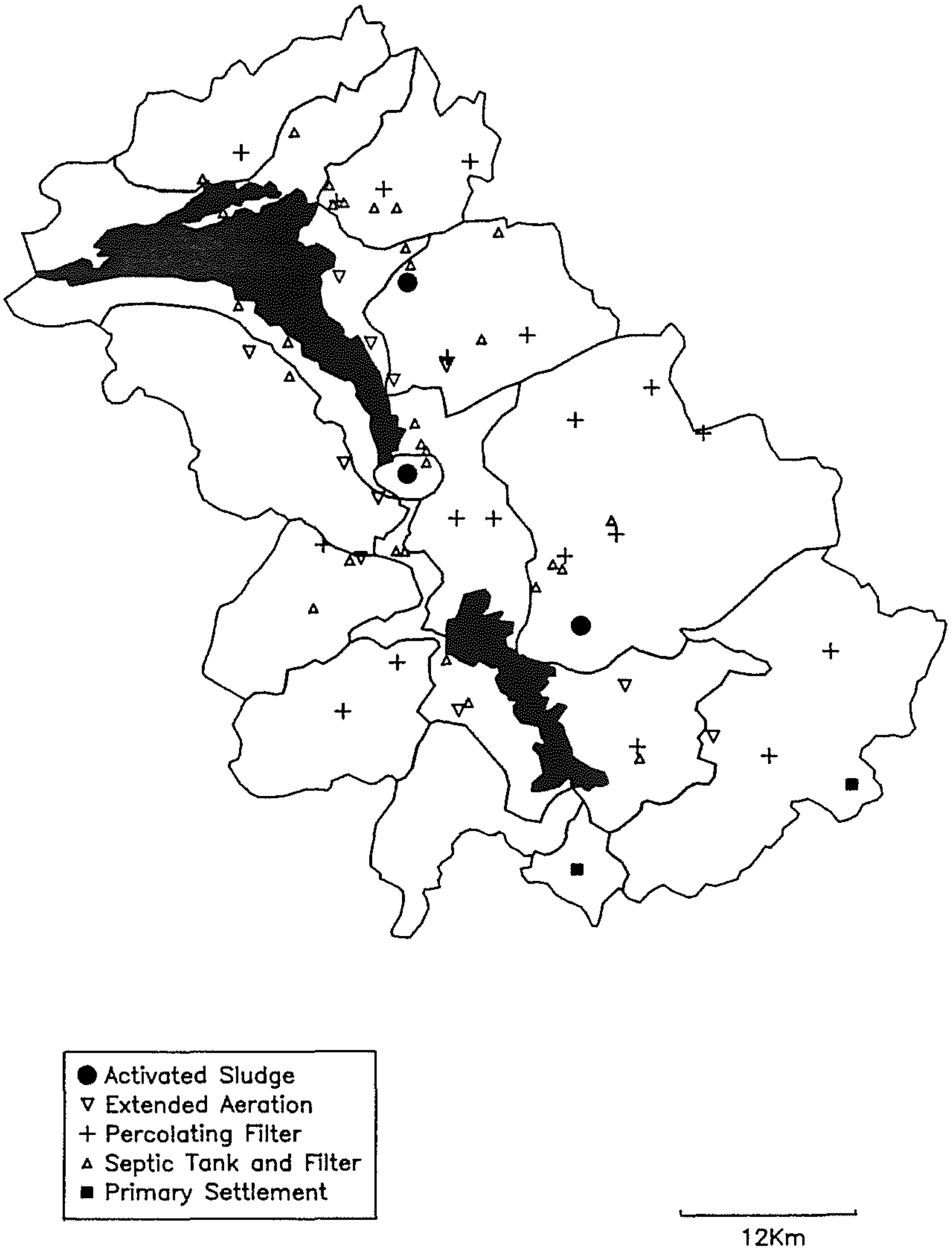
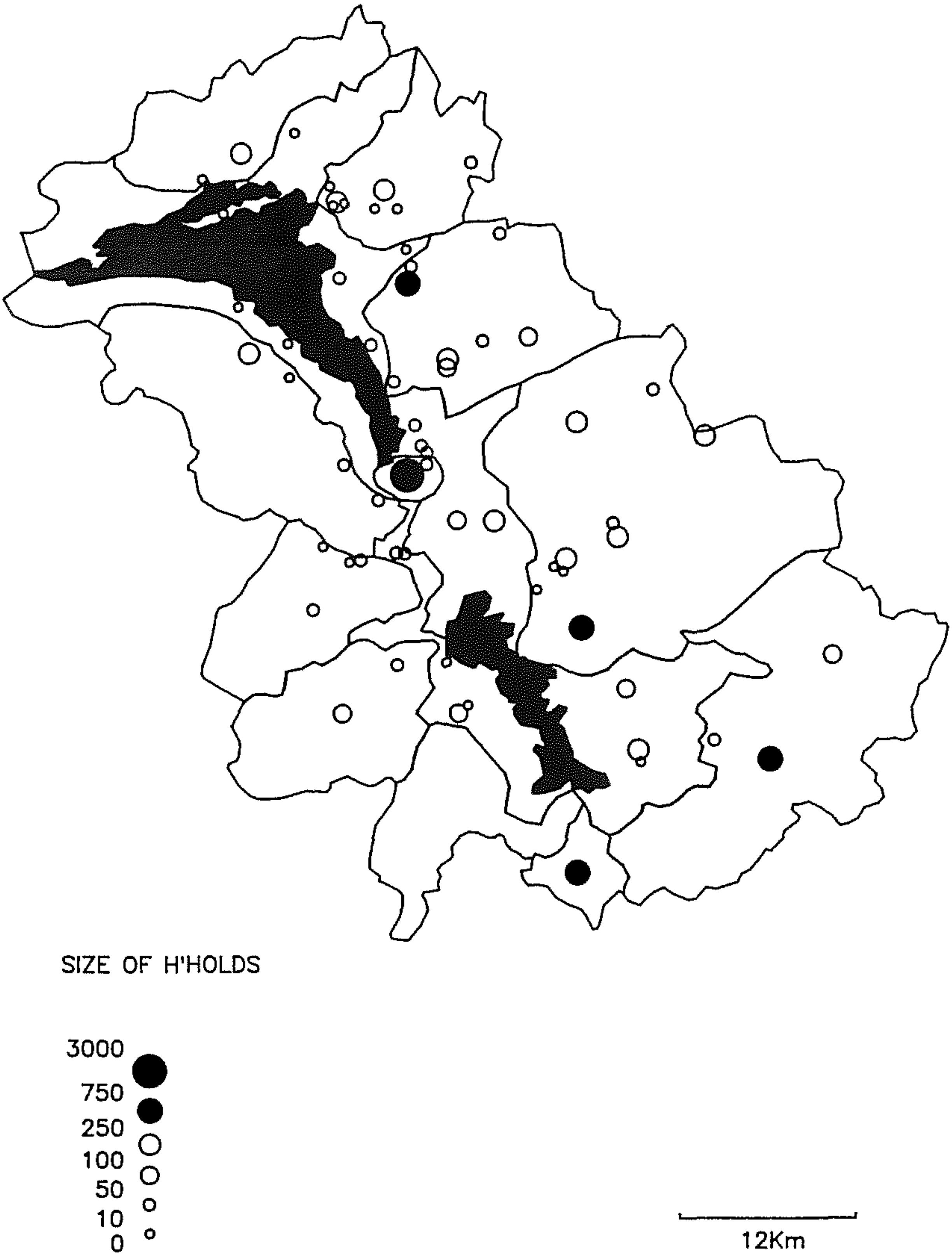


Fig. 5 SIZE OF SDWS (HOUSEHOLDS SERVED) 1976



3. INCIDENTAL P LOSS

In both primary and secondary treatment processes P removal occurs through the separation of solids from the waste stream being processed (Jebens 1970). In primary sedimentation P associated with existing solids is removed by settling, whereas in secondary biological treatment P is removed through its conversion by biological and/or chemical processes into a solid phase, followed by the removal of this phase from the waste stream.

To assist with the determination of representative figures for incidental P removal in the SDWs of the study area, the following section examines the processes involved by means of an extensive review of the literature.

Data from the literature relating to incidental P removal is presented in Appendix 1. In addition, the Divisions of all water authorities in the U.K. were circulated and asked to provide data on P levels through SDWs. Fifteen Divisions were able to provide such information; however, in only five cases was this data in the form of total P (TP) (App. 2). Because of the behaviour of different P forms in sewage, especially the tendency of conversion to soluble forms, and the hydrolysis of condensed phosphates, (e.g. Davis and Wilcomb 1967, Cooper and Bailey 1973, Devey and Harkness 1973), and because of difficulties in comparing soluble P data presented in terms of concentration, rather than loading, it is desirable for reasons of comparability, to examine the TP fraction. The concern of water authorities with soluble forms is of course a result of the predominant role of this fraction in the enhancement of algal growth. Thus the data, published and unpublished, in Appendices 1 and 2 and summarized in Tables 2-4, relates only to TP. In addition, the figures for removal in secondary stages of treatment are standardised as the cumulative reduction achieved from primary and secondary stages.

Despite these precautions a great variation in removal rates is apparent from both published and unpublished data. In part, this is a result of real differences, incurred through variations in operating methods and efficiencies, and in the nature of the influent sewage. However, to some extent, such differences may reflect variations in sampling procedure, P analysis and the format of presentation employed.

Schaffner and Oglesby (1978) recognise that to account for the diurnal and seasonal variations exhibited in the performance of SDWs, extensive sampling programmes are ideally required. The use of discrete or spot sampling to produce information that is considered to represent conditions of 24 hour flow through a SDW, may lead to erroneous conclusions regarding the true situation (Harrington 1980). Difficulties from discrete sampling may also occur through the storing of samples before their analysis, although this should have little effect on the TP fraction. Different methods of analysis may also confuse the real situation. Stones (1956b) in a series of experiments with various effluents, was particularly critical of the method used to analyse P in the samples.

At smaller SDWs continuous sampling may be of little benefit. The Anglian Water Authority (1983) encountered conditions of flow followed by no flow at small SDWs. As a result, samplers failed to operate on occasions and a great variation in the chemical composition of influent sewage was recorded. Grampian Regional Council (Robinson personal comm. 1983) encountered similar problems at their small SDWs.

Care must also be taken in interpreting data that is presented in terms of P concentration rather than loading. Soluble fractions in particular are susceptible to misinterpretation as a result of dilution which may occur within the SDW.

Results obtained from laboratory as opposed to plant scale experiments may not conform to practical operating conditions, whilst an experiment of any kind may not directly relate to results achieved in daily SDW operation.

With the above considerations in mind, the data portrayed in Appendices 1 and 2 and Tables 2-4, is thus presented as a guide rather than a rubric of incidental P removal at SDWs.

3.1 Primary Treatment

In primary settlement P reduction is limited to those forms that are insoluble and settleable. Because only gross solids are removed at this stage, the incidental removal of P is potentially low, the majority of P in sewage being associated with non-settleable matter (Wilson 1976, Gray 1981). Particle size, together with flow in terms of the hydraulics of sedimentation in primary tanks, is an important consideration. Sewer length, the degree, if any, of pumping, the amount of dilution afforded incoming sewage, (determined largely by the extent to which crude sewage is separated from storm water) will all affect the amount of biodegradation and particle breakdown in the influent. Jenkins and Menar (1967) recognise that P removal at this stage is proportional to suspended solids (SS) removal, and that for a typical raw sewage of 10 mgl P, on average 10% P loss is observed in Northern Ireland. Gray (1981), considers this figure to vary between 0 and 5%. Melkersson (1973) found 5% - 15% loss at the mechanical sedimentation stage of sewage treatment in Sweden, a range supported by Sedlak (personal communication 1983).

Whether P settled to the primary sludge constitutes net removal from the system depends on the regime in which primary clarifiers are maintained. Stones (1956a), who achieved 29.9% P loss in experiments with primary sedimentation, determined that during this process sewage with a BOD of 300 ppm. requires 40 ppm. of oxygen to maintain aerobic conditions during 18 hours of settlement. Failing this, biological activity becomes anaerobic, creating conditions favourable to the release of P incorporated in the settled sludge back into the waste stream.

In his investigation of the activated sludge process Dobolyi (1973), did not examine P removal in the primary sedimentation stage because of complications engendered from the contribution of P from decomposing sludge back to the primary effluent.

The variation of incidental P removal at the primary stage apparent from Appendices 1 and 2, may be ascribed in part to the differing characteristics of influent sewages. For example, Harkness and Jenkins' (1958) figure of 20.6% was undoubtedly influenced by the metal content of industrial wastes, encouraging the precipitation of P in the settlement process (Bayley 1970). Similarly, a part of the variation may be explained by differences in the design of settlement tanks and the period of retention of sewage within them.

3.2 Secondary (Biological) Treatment

Much of the literature on incidental P loss in this stage of treatment is concerned with explaining abnormally high P losses occasionally observed at SDWs, particularly with a view to harnessing the mechanisms involved to promote enhanced P uptake in SDWs where tertiary treatment is required to decrease P levels. Because of the greater potential for enhanced P removal in the activated sludge process (see below), this process has received much greater attention than the percolating filter (Jebens and Boyle 1972). Zanoni (1973) in observing the serious dearth of information regarding the effectiveness of percolating filters, claims that they are almost totally ignored in studies dealing with P removal.

By their very nature, biological stages of sewage treatment result in incidental P loss to satisfy the nutritional requirements of micro-organisms (e.g. Bayley 1970, Wilson 1976). However, the degree of removal is limited by the fact that most sewages, particularly domestic sewage, are nutritionally unbalanced for the requirements of heterotrophic bacteria, in that they are deficient in carbon (C) but rich in nitrogen (N) and P (e.g. City of Baltimore 1970, Stumm 1973, Wilson 1976). Bayley (1970) recognised that because a supply of P is essential for growth, biological treatment results in the assimilation of some P in new cell material. However, in most cases, it was seen that P supply exceeded demand.

The dependence of P assimilation efficiency on the C:P ratio in wastewater is seen in the greater P losses observed in wastes with a high ratio of assimiable C to P, such as those produced from sugar processing (Albertson and Sherwood 1969). On occasions, an addition of nutrients may be necessary to maintain minimum nutritional requirements in such wastes. Sawyer (1944) has suggested that specific industrial wastes should be utilised to increase the carbohydrate content of sewage, specifically to enhance P assimilation.

Because micro-organisms contain relatively consistent quantities of C:P:N, the biological uptake of P can be related to the quantities of biosolids produced. Black (1980) observes that assuming a solids yield of 0.5 g volatile suspended solids per g.BOD removed, approximately 0.5 - 1 g of P will be removed per 100 g of BOD. In normal municipal wastewater with 90% - 95% BOD removal, this yields a 20% - 40% decrease in P.

The reason for percolating filters removing less P than activated sludge plants is explained by Goodman and Mikkelson (1970) in terms of the lesser amounts of solids produced in the percolating filter per unit weight of BOD removed. In a series of percolating filters in Milwaukee, Zanoni (1973) found that P removal was generally less than 20% in the biological stage.

The relationship between P and BOD removal has been recognised by other researchers e.g. Owen (1953), Nesbitt (1966), Gray (1981) and Arvin (1983). A generally acceptable ratio of 100:1 for BOD:P removal for 'normal' sewages is proposed by Pieczonka and Hopson (1974) and Gray (personal communication 1983).

Jenkins and Menar (1967) used a series of kinetic equations to predict P loss from sewage in the activated sludge process. Assuming:

1. P is only removed by metabolic incorporation into activated sludge cells, i.e. growth.
2. At steady state activated sludge takes up P by an amount proportional to the net amount of cells formed.
3. P content of activated sludge cells remains constant over a wide range of organic loadings.

Then under practical operating conditions the maximum possible P removal at the biological stage was 20%. However, as the wide range of figures for all secondary treatments in Appendices 1 and 2 attest, a figure of 20% is not always found in reality.

Abnormally high P removal rates have been observed at certain activated sludge plants. The best documented example is that at San Antonio, Texas, which regularly achieved 80% P removal (Vacker et al 1967). Two schools of thought seek to explain the phenomenon of enhanced uptake.

One suggests that operating conditions within the SDW cause the activated sludge to assimilate more P than is required for growth. In laboratory and plant experiments Levin and Shapiro (1965) explained abnormal P assimilation in terms of the 'luxury uptake' of dissolved ortho-P by sludge organisms, that is uptake in the absence of growth. They postulated a vital role for dissolved Oxygen (DO) concentration in the aeration basin. At sufficiently high aeration rates luxury uptake of P would occur, but conversely, when aeration rates fell, dissolved inorganic P would rapidly leak out of sewage organisms.

Feng (1962) suggests that enhanced uptake may occur when conditions are particularly favourable for biological activity - temperature near 25° C, adequate rates of aeration and suitable ratios of organic material: activated sludge. Bayley (1970) summarises the operating conditions which have apparently stimulated 'luxury uptake' as high rates of aeration and a level of DO above 1.5 mgl, low BOD and SS levels in final settled effluent, and a daily loading equivalent to 0.5 kg.BOD.per kg.SS in the aeration tank.

Marais _et al_ (1983) claim that cumulative evidence exists to support the role of biological mechanisms in producing enhanced uptake. However, they recognise that the theoretical description of the processes involved are, in a biochemical sense, still at a rudimentary stage.

A second theory denies any role for 'luxury uptake' and ascribes enhanced P losses to the precipitation of metal phosphates in hard water sewages, followed by the enmeshing of the precipitate in the activated sludge floc. Jenkins and Menar (1968) reveal that calcium phosphate precipitation in activated sludge mixed liquor and effluent is largely determined by the CO2 content of the mixed liquor. High DO levels have no direct effect on the process except to serve as an indication of low CO2 content in the aerating air and high P.H. of the mixed liquor. The high removals reported by Levin and Shapiro (1965) are discounted by Menar and Jenkins (1968) because of the transitory nature of the process operating in the laboratory scale, batch operated plants that were used. Riding and Elliott (1979) are similarly critical of Levin and Shapiro's work. From laboratory experiments they conclude that any enhanced uptake of P in activated sludge is a result of chemical precipitation.

A pilot plant was constructed (Menar and Jenkins 1969) to conform to the operating conditions of the San Antonio plant at which enhanced P removal was first documented (see above). P decrease of only 19.7% was observed in these experiments. The authors ascribe the high rates obtained at San Antonio to the high levels of calcium, aluminium, zinc and iron in the plant influent. All these metals form sparingly soluble phosphates at typical mixed liquor P.Hs. In a rare observation of enhanced P uptake in percolating filters, Jebens and Boyle (1972) similarly considered the dominant influence to be the chemical precipitation of P with cations in hard water.

Enhanced P removal without the aid of additional processes only occurs at a few SDWs and is not general, indicating that some SDWs operate under specific favourable conditions (Jones 1973). However, as Finger et al (1974) recognise, experiments have proved inconclusive as to the respective role of 'luxury uptake' and chemical precipitation. Barnard (1983) considers that a concensus is developing that both mechanisms are involved.

Recognising that a scattering of operating data relating to incidental P removal, of 15% - 50% in activated sludge plants was affected by variations in wastewater characteristics and sludge types, Albertson and Sherwood (1969) observed that P is assimilated to different extents in different types of activated sludge plants according to aeration rates and sludge age. High rate systems coping with strong organic loads, employing sludge with an age of 1-2 days, result in the highest BOD:P removal. Conventional activated sludge plants with a sludge age of 3-5 days produce a BOD:P removal of 100:1. Extended aeration systems where sludge age may exceed 20 days, produce much lower P removals in the range BOD:P of 250-500:1. Enhanced P removal has been observed at extended aeration plants (e.g. Kerdachi and Roberts 1980), but only where such a SDW has operated under exceptional conditions.

Whether a SDW is achieving enhanced P removal or not, a variety of operating conditions and methods may affect the reduction achieved. One study (University of Texas 1971), achieved occasional through plant reductions of 30% - 40%. but the average was only 10% - 15%. The variation was explained by the difference in loadings between wet and dry weather; plant efficiency, for example, clarifiers were occasionally out of action, and particularly sludge handling methods (also see e.g. O.E.C.D. 1974).

3.3 Sludge

All P removed in SDW processes, whether by mechanical, biological or chemical means, is received into the sludge. In sedimentation and percolating filter SDWs, sludge from primary and secondary settlement is drawn off as waste. In the activated sludge process a certain amount of secondary sludge is returned to the aeration basin to maintain activated sludge levels (see page 5).

It has frequently been observed that if oxygen becomes deficient and low redox conditions occur in and around the sludge floc, whether in clarifiers or aeration chambers, then ortho-P is released back to its soluble form (e.g. Wells 1969, Jones 1973). Hulcher et al (1971) observe that most activated sludge plants are characterized by a decrease in P concentrations during aeration, followed by an increase during final clarification. Levin and Shapiro (1965) and Shapiro et al (1967) observed that with the onset of anaerobic conditions P release follows rapidly. Randall and Marshall (1970) show that the major portion of soluble P is released within 90 minutes of anoxic conditions being reached, at a rate of release directly related to the magnitude of uptake prior to release.

Methods of sludge treatment may also be responsible for reintroducing soluble P either to the SDW influent stream, or as a subsidiary effluent. De-watering processes, such as pressing or heat treatment, may release P back to a soluble phase, while chemical or polymer treatment may then negate this process (e.g. Davis personal communication 1983). Anaerobic digestion of sludge produces a supernatant liquor rich in soluble P. The recycling of this liquor to the primary or secondary waste stream produces an increased P loading on the SDW and effectively reduces the net P removal achieved within the plant (e.g. Jebens 1970, University of Texas 1971, and Wilson 1976).

Without a consideration of sludge handling techniques P loss figures may prove misleading, for example, Bayley (1970) observes that in all SDWs where 'luxury uptake' has been reported, supernatant liquors from anaerobic sludge digesters have been treated in systems quite separate from the main plant.

Hemens (1968) takes the point one stage further. In recognising that P is only removed from the SDW system in dried sludge, and that the P content of dried sludge is usually low, SDWs employing sludge digestion, in his opinion, merely act as delaying systems for P, in that almost all the amount entering the system will eventually be discharged in the effluent.

TABLE 2. SUMMARY OF PUBLISHED 'INCIDENTAL' P LOSS DATA

	N. IRELAND			EXCLUDING N. IRELAND			TOTAL		
	Observations	Range %	Mean %	Observations	Range %	Mean %	Observations	Range %	Mean %
PRIMARY SEDIMENTATION	1		5	14	2-29.9	14.3	15	2 -29.9	13.7
PERCOLATING FILTER	10	0-15	10	13	12-27	17.2	23	0 -27	14.1
ACTIVATED SLUDGE	5	4.9-23	16.4	25	15-87.5	37.9	30	4.9-87.5	34.3

TABLE 3. SUMMARY OF UNPUBLISHED 'INCIDENTAL' P LOSS DATA

	N. IRELAND			EXCLUDING N. IRELAND			TOTAL		
	Observations	Range %	Mean %	Observations	Range %	Mean %	Observations	Range %	Mean %
PRIMARY SEDIMENTATION	1		2.5	2	10.2-11.7	11	3	2.5-11.7	8.1
PERCOLATING FILTER	8		21.3	7	0 -27.6	23.9	15	0 -27.6	22.5
ACTIVATED SLUDGE	1		31.5	10	0 -46.9	21.3	11	0 -46.9	22.2
SEPTIC/ SEDIMENTATION TANK + FILTER				6	0 -24.2	11	6	0 -24.2	11
EXTENDED AERATION				4	0 -20.7	10	4	0 -20.7	10

TABLE 4. SUMMARY OF PUBLISHED AND UNPUBLISHED 'INCIDENTAL' P LOSS DATA

	N. IRELAND			EXCLUDING N. IRELAND			TOTAL		
	Observations	Range %	Mean %	Observations	Range %	Mean %	Observations	Range %	Mean %
PRIMARY SEDIMENTATION	2	2.5- 5	3.8	16	2-29.9	13.9	18	2-29.9	12.8
PERCOLATING FILTER	18	0 -21.3	15	20	0-27.6	19.5	38	0-27.6	17.4
ACTIVATED SLUDGE	6	4.9-31.5	18.9	35	0-87.5	33.2	41	0-87.5	31.1
SEPTIC/ SEDIMENTATION TANK + FILTER				6	0-24.2	11	6	0-24.2	11
EXTENDED AERATION				4	0-20.7	10	4	0-20.7	10

4. INCIDENTAL P LOSS AT SDWs IN THE STUDY AREA

Representative figures for incidental P loss at the various SDWs in the study area were determined after considering the data presented in Appendices 1 and 2 (summarised in Tables 2-4), together with variations that may be attributed to operating methods and conditions as discussed in the previous section. The data in Tables 2-4 portray a wide range of values for all types of treatment and, as such, the means are of little value. The figures relating to Northern Ireland are, however, somewhat less widely spread, and for the three processes documented (primary sedimentation, percolating filters, and activated sludge), somewhat lower than those from other sources.

Determination of representative figures would have been assisted if sampling of influent and effluent P was carried out at SDWs within the study area. In recent months spot sampling of effluent for soluble P analysis has been instigated at certain SDWs. However, without information on influent loads or concentrations, such data is of little value. This data does reveal, through the wide range of values observable within the same SDW, the inadequacies of spot sampling.

Similarly, no concise source is available relating to the efficiency of BOD reduction at SDWs. Given the broad BOD:P relationships discussed on pages 13-14, such information would permit a general overview of potential P reduction. BOD data that is occasionally reported in miscellaneous D.O.E. files at Enniskillen Sub-Division of the Water Services, points to a great temporal variation in performance within a SDW and between different SDWs. In part, this is another result of uncalibrated sampling, but SDW managers recognise that mean plant performance figures hide great variations in diurnal plant efficiency (D.O.E. personal communication 1983).

A survey of SDWs in the Enniskillen Sub-Division (D.O.E. 1974), provides a subjective assessment of general plant efficiency and equates the equivalent population served with design capacity (see Table 1). Of the 38 major SDWs assessed within the study area 22 were considered to be operating satisfactorily, while 16 were overloaded and operating below standard. Some works such as those at Newtownbutler, Springfield, Tamlaght and Tempo were described as "badly overloaded". Plant overloading suggests that a unit of P will pass more quickly through a SDW, as sedimentation periods decrease, storm overflow is more frequent and filters become overloaded, less of it being assimilated into the sludge.

The great majority of SDWs in the area are small and maintained by travelling shifts of workmen. Permanent staff are engaged only at the Enniskillen and Lisnaskea works. Under such conditions maintenance problems are more likely to occur and a greater period may elapse before they are rectified. It has been noted that P release from sludge rapidly follows the onset of anaerobic conditions in clarifiers (see page 17). Such conditions are more likely to occur, and take longer to recognise, in the absence of constant supervision.

At present the three activated sludge plants, serving the largest populations in the Northern Ireland section of the catchment, at Enniskillen, Lisnaskea and Irvinestown, work efficiently. Lisnaskea achieves a Royal Commission BOD:SS 10:10 standard effluent, while Enniskillen and Irvinestown achieve 20:30 standards (Davis personal comm. 1983). Problems have occurred in all three plants within their short history. At Enniskillen occasional problems with sludge quality have materialised. At Irvinestown mechanical difficulties with sludge return pumps have, on occasion, caused the whole system to collapse. At Lisnaskea legal action resulted from the excess discharge of creamery effluent to the plant.

Very little trade effluent is discharged to SDWs in the study area generally. However, certain plants receive heavy loads of creamery effluent (e.g. Irvinestown, Lisnaskea, Derrygonnelly and Fivemiletown), or abattoir effluent (Enniskillen). Such effluent imposes heavy BOD and SS loads on the SDWs, for example in 1974 Enniskillen abattoir was permitted to discharge waste up to 2400 ppm BOD and 2000 ppm SS, and Derrygonnelly creamery 860 ppm BOD and 780 ppm SS (D.O.E. 1974). In terms of P removal the reduction of such BOD and SS loads to Royal Commission standards is compensated for by the P rich nature of the wastes in question, and is thus not excessive.

Tertiary treatment for P removal is not practised at any SDW in the study area, although in 1982 trials of such a process were initiated at Enniskillen. Some SDWs do employ a tertiary stage designed for the 'polishing' of effluents. Most often this consists of irrigating secondary effluent through grass plots, and is to be found at small SDWs. At Lisnaskea activated sludge plant, an upward flow pebble bed clarifier is employed for tertiary polishing which partly accounts for the superior 10:10 standard of effluent. Although there is no documented information on the effect of these processes on P content of effluent, both grass and pebble bed clarification can, in theory, be expected to reduce the P content of secondary effluent to an unknown extent.

At no SDW in the study area is sludge treated by anaerobic digestion. Since 1980 <u>all</u> waste sludge produced in the Enniskillen Sub Division has been transported to the sludge presses at Enniskillen SDW for treatment. The pressed sludge is disposed of as landfill or dumped, whilst liquor from the presses is returned to the head of the works (Irvine personal comm. 1983). Although less P may be released from sludge during pressing as opposed to during digestion, the 12,000 gallons of wet sludge tankered daily to Enniskillen could represent a substantial transfer of P between the catchments of the study area, and in particular increase the loading at Enniskillen SDW. However, the use of polymers to enhance the de-watering process at Enniskillen may counteract any increase in loading, encouraging sludge P to remain coagulated in its solid state (Davis personal comm. 1983).

Before 1980 sludge was treated at each SDW on an individual basis. Little documentation exists to detail individual cases. In general, liquid sludge was either dried on sludge beds, the liquor allowed to run off, and the dried product disposed of as landfill, or the liquid sludge was spread on to the land for manurial purposes. [In 1978 2302.8 gallons of liquid sludge were disposed of to land in the Enniskillen Sub Division (D.O.E. misc.)]. In both cases the net removal of P in the treatment process was unaffected by recycling of sludge liquor.

The above discussion was drawn from information relating to the section of the study area in Northern Ireland. Responsibility for SDW management in the Republic is less clearly defined and details of operating conditions less accessible. In 1976 there were only five SDWs in the Republic section of the study area (see Table 1), none of which may be considered to have operated any differently or more efficiently than their counterparts in the North.

Table 5 portrays two series of data compiled with due consideration of the information from Appendices 1 and 2, particularly that relating to Northern Ireland, consideration of circumstances outlined in the above discussions (pages 9-25) and after consultation with D.O.E. managers in Northern Ireland. This data is to be utilised as scenarios for incidental P removal at SDWs in the study area since 1951. Scenario two represents the optimum reductions possible given maximum efficiency of SDW operation. Scenario one represents the level of P reduction more probably achieved at

SDWs in the area, the difference being apparent in the lower losses postulated for percolating filters (10% net) and Activated Sludge Plants (15% net). Even this may be optimistic (e.g. Gould personal communication 1983), and when sewage derived P loadings to Lough Erne are finally calculated, a third control scenario assuming no net P removal at SDWs, will be additionally examined (Scenario 3 in Table 5).

By including a consideration of incidental P loss at SDWs in calculating P loadings to the lake, such loadings will comprise a more realistic assessment of the P input from sewage to a waterbody than has been achieved in other non experimental studies.

TABLE 5. SCENARIOS OF INCIDENTAL P LOSS AT SDWs IN THE LOUGH ERNE REGION

	Scenario 1	Scenario 2	Scenario 3 (Control)
	%	%	%
PRIMARY SEDIMENTATION	5	5	0
PERCOLATING FILTER	15	17.5	0
ACTIVATED SLUDGE	20	25	0
SEPTIC/ SEDIMENTATION TANK + FILTER	10	10	0
EXTENDED AERATION	10	10	0

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APPENDIX 1. INCIDENTAL P LOSS: PUBLISHED DATA (PERCENT LOST)*

SOURCE	PRIMARY SEDIMENTATION	PERCOLATING FILTER	ACTIVATED SLUDGE	GENERAL ASSUMPTION[1]
Williams + Coker (1981)		25	40	
Owens + Wood (1968)				50
D.O.E. (1971a)		42		
D.O.E. (1971b)	27			
Forziati (1972)		15	15	
Vollenweider (1971)				50
Gilbert + De Jong (1978)	20			35
Schaffner + Oglesby (1978)	10			30
Graham (1967)				33
Perry *et al* (1975)	28		48	
Truesdale + Taylor (1975)				<50
Bouldin *et al* (1975)				0
Finstein + Hunter (1967)				little effect
Caster + Jacobs (1975)				10
Porter (1975)				20
Stumm (1973)				40
Dobolyi (1973)			16	
Collingwood (1978)				40
Jenkins + Lockett (1943)				46 60
Min. Technol. (1967	10			
City of Baltimore (1970)			25	
Wuhrman (in Vollenweider)			25	
Finger *et al* (1974)			19.7	
Hurwitz *et al* (1965)			57	
Vacker *et al* (1967)		12	87.5	
		17	41	
		15	50.5	
		15.5	46	
			29	
De Pinto *et al* (1980)	12.9			
Zanoni (1973)		15		
Barth *et al* (1969)	5.3	13		
Heinke + Norman (1969)	10.5		56.5	

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*All secondary treatment figures include losses at the primary stage where appropriate.

[1] Also includes results of secondary treatment studies where the type of process is unspecified.

APPENDIX 1 cont.

SOURCE	PRIMARY SEDIMENTATION	PERCOLATING FILTER	ACTIVATED SLUDGE	GENERAL ASSUMPTION[1]
Owen (1953)	3.1 2.0		42	19 11 46 41 20
Jebens (1970)		20		
Harkness + Jenkins (1958)			27.5 52.7 24.5 38.7	
Stones (1956a)	29.9	14	67.5	
Jones (1973)			18	
Nesbitt (1966)			28	
Sedlak (p. comm. 1983)	10		25	
De Renzo (1978)		27 19		
Jenkins + Menar (1967)	10		30	
Menar + Jenkins (1969)			19.7	
NORTHERN IRELAND				
Smith (1977)		18	23	
Wilson (1976)		18 9 7.3 6.9 14.4 13.1 8.8 7.3 0	16 15.2 4.9 23	
Gray (1981)	5	15		

APPENDIX 2. 'INCIDENTAL' P LOSS: UNPUBLISHED DATA (PERCENT LOST)*

SOURCE	PRIMARY SEDIMENTATION	PERCOLATING FILTER	ACTIVATED SLUDGE	SEPTIC/ SEDIMENTATION TANK + FILTER	EXTENDED AERATION
ANGLIAN WATER AUTHORITY	10.2	23.9	34.7	22.5	0
	11.7	27.5		3.8	19.4
		15.8		8	0
		23.6		7.7	
		0		24.2	
				9	
THAMES WATER AUTHORITY			40.2		
NORTH WEST WATER AUTHORITY		27.3	7.1		
		27.6	12.5		
			46.9		
			16		
			9.1		
			0		
			24.1		
			21.9		
N. IRELAND N. DIVISION	2.5	21.3 (mean of 8 SDWs)	31.5		
GRAMPIAN WATER COUNCIL					20.7
CENTRAL REGION WATER COUNCIL		25.6			

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*Where appropriate, all secondary treatment figures include losses at the primary stage.

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