ESTABLISHING PHOSPHORUS FLUXES THROUGH MATERIAL FLOW ACCOUNTING AND SYSTEMS THINKING IN AN URBAN-SHED IN HARARE, ZIMBABWE

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ABSTRACT

Phosphorus (P) resources globally are considered limited. P originates from a mined non-renewable rock, therefore its presence in the urban-shed demonstrates the impact of urbanisation and the anthropogenic influences on natural cycles of material flow. Any recycling of P is therefore becoming increasingly important. In passing through the linear urban system P is mobilised from particulate to soluble forms. With the present level of nutrient losses from urban water management into the aquatic environment (leading to adverse health and ecological impacts) commitment to urban or peri-urban ecological agriculture (without synthetic fertilisers) offers an attractive solution to the management of urban organic "wastes". The macro-nutrients stemming from human metabolism contained mainly in urine are of particular interest. Sustainable "Urban Drainage System" (UDS) technology should support closing of cycles of natural resources such as nutrients in urban water management. This paper describes a case study in Harare, Zimbabwe, where tracking of P-bearing materials and fluxes of P within the UDS is being conducted. The focus of the methodology is on spatial and time segregation of the different fractions of urban waste flows and the urban water cycle. The tools used include Material Flow Accounting/Analysis (MFA) and mass balancing techniques. The study seeks to establish a clear pattern of flow of water and matter (P-bearing materials in particular) through a regional economy and the options of short-cutting or closing the open-ended flows.

KEYWORDS

Material flow accounting; Phosphorus fluxes; systems thinking; urban agriculture; urban-shed; urban water cycle

INTRODUCTION

Urbanisation of the anthroposphere has produced a high density of energy and material fluxes, i.e. a high metabolic rate. It is clear that the state of the knowledge on the complex metabolism of the ecosystems is not yet sufficient to comprehend all the synergistic and antagonistic effects of anthropogenic material fluxes on the environment. The city, with its wastewater and other infrastructures, sits within an industrial-urbanised ecology of individual entities arranged one to another and bound together in a web of energy and material flows. In an ideal world the "waste" residue from the metabolism of one of these entities would become the feedstock of another (Ausubel, 1992).

Conventional economics emphasises the seemingly self-generating flows of money between firms and households in the marketplace. It thereby fails to account for either informal work or the value of ecological services, and is blind to the irreversible unidirectional material flows that sustain the economy

(Wackernagel & Rees, 1996). The circular economic flows are actually sustained by the unidirectional throughput of ecological goods and services from and to the ecosphere (the "natural income" stream). All the energy and much of the matter that passes through the economy is permanently dissipated into the environment never to be used again. This state of affairs is illustrated by Fig 1.

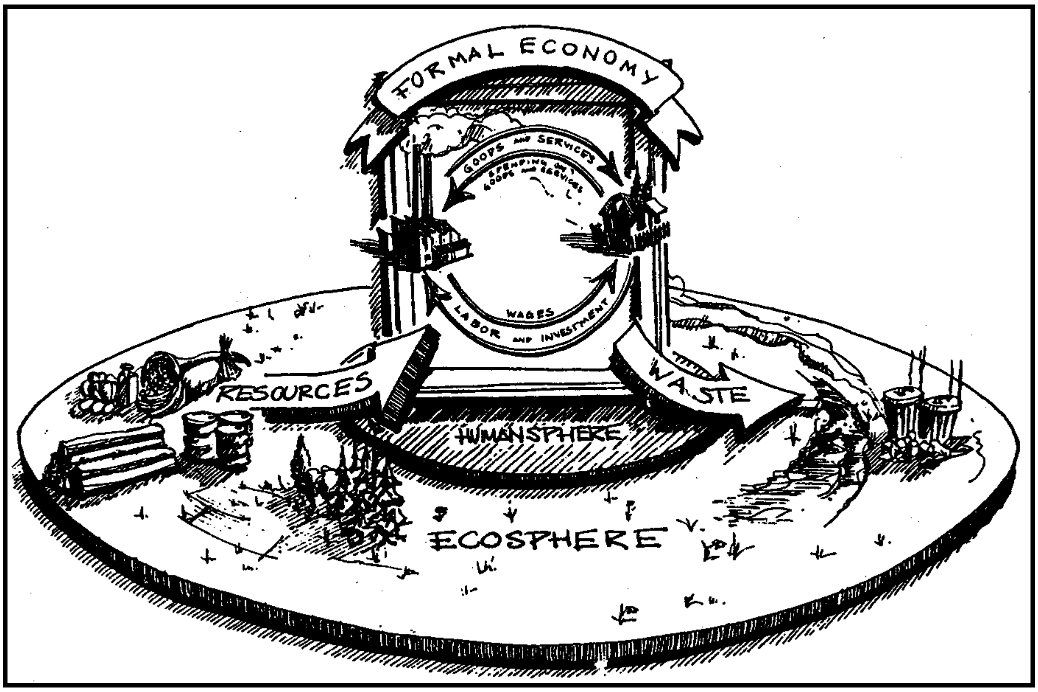


Fig 1 The ecological worldview (Wackernagel & Rees, 1996)

The urban drainage system (UDS) serving today's urban communities range from rudimentary, unlined, open channel drains to highly engineered, expensive, piped sewer systems. In both cases, water provides an apparently convenient mechanism for transporting waste away from areas of human habitation, where it would otherwise cause illness and diseases or disrupts the operation of other urban services. An important realisation in the puzzle is that UDS's are intrinsically linked to other components of the natural water cycle (Butler and Parkinson, 1997).

Therefore the way how the UDS is arranged and how it behaves is a point of focus. The principal nutrients (Phosphorus and Nitrogen) flow in a circular, closed loop system in nature, but we perceive of nutrients in a linear, open-ended system. The danger is that once one closed loop system is opened, it may force open other closed loop systems elsewhere in the ecosystem (Esrey, 1998). Short-cutting or closing P-cycles in the urban environment is closely related to closing of water cycles. New solutions in terms of UDS for sustainable cities of the future are perceived to be source orientated, non-mixing, ecologically sound, local and small scale.

This paper outlines the methodology and preliminary results of an on-going study on P-fluxes being carried out at Mufakose high-density and Marimba middle-density suburb within the City of Harare in Zimbabwe. The micro-study catchment was selected because of a number of reasons. The most important ones being that it lies within a distinct hydrological boundary and the sewage and storm flows emanating from this regional economy could be isolated and characterised adequately. Catchment areas are generally not used for administrative purposes, but they are the base for natural flows. A catchment area is indeed the meeting place between society and the physical reality, and thus more appropriate in

MFA. Secondly Mufakose suburb is one of the high-density areas in Harare, which was established in the 1960's, with the aim of housing low-income workers. Due to high unemployment rate in the recent years a significant number of households have resorted to both legal and illegal urban agriculture in order to improve the household food security.

Since cities need to close the open loop of limited resources such as P, urban agriculture seems to be an option in closing the open loop by reusing and transforming the by-products of human metabolisms especially, which, usually are dumped as polluting waste into the bio-region. The importance of the research and this paper is to reveal and demonstrate the links between urban food production, urban agriculture, urban poverty, resource recovery and sustainable urban planning and development. The analysis of P-fluxes in urban systems provides an indication where technological interventions can be inserted in the new look UDS. The perceptions gained by material flux analysis enables a control on regional material fluxes and the development of kybernetic strategies for the metabolic evolution of the anthroposphere (Baccini & Brunner,1991).

RESTORING THE PHOSPHORUS CYCLE

Origin and exploitation of P

Phosphorus is the eleventh most common element on Earth, essential to all living organisms. In particular, alongside nitrogen, it is one of the main plant nutrients. In nature, phosphorus always occurs combined with oxygen and other elements, forming phosphates. Phosphate resources are located in the earth's crust in the form of phosphate rock. Around 80% of phosphates produced by the world's industry today are used in fertilisers, with a further 5% being used to supplement animal feeds, 12% in synthetic detergent manufacture and only about 3% of the total consumption is used in diverse applications as metal surface treatment, corrosion inhibition, flame retardant, water treatment and ceramic production. The main commercial deposits are located in Morocco, the USA, the former Soviet Union, China and South Africa. The known reserves of currently exploitable phosphate rock are estimated at about 40 billion tonnes. At the peak of rate of consumption (150 million tonnes per year) these reserves will last more than 250 years (CEEP & CEFIC, 1997). Whilst there appears to be no supply "crisis" for the phosphate industry's main raw material (phosphate rock), it is still clear that reserves are finite.

Fate of P in urban drainage systems

In their natural cycles P-bearing materials, are not easily degraded into soluble forms. They have a strong affinity for binding onto particulate matter, or are themselves insoluble, so the P tends to accumulate in soils or sediments, a state of relative immobility notably maintained by sufficient presence of oxygen. Flows of P into the city, in the form of food, fertilisers and detergents, are predominantly derived originally from mined sources; in passing through the city and into the urban drainage system they undergo a significant change of state, from particulate to soluble forms; they are thereby mobilised and thus "diverted", as it were, into the (terrestrial) aquatic environment. The net result is the all too familiar problem of eutrophication in freshwater systems (Beck *et al*., 1994).

Through the natural cycles of the aquatic environment the associated flux of P will ultimately be immobilised once more in particulate forms and be deposited in sediments. In this location, however, the P-bearing materials will reside in a far less stable condition than the land environment. The relatively low oxygen-carrying capacity of shallow water bodies will promote probability of anaerobic conditions occurring, with the consequent re-mobilisation of P into soluble form.

Once arrested in a well-aerated soil, P-bearing materials are known to be rarely leached into underlying ground waters. On this basis, land systems would once more appear to be the preferred destination of the

P fluxes passing through a city, notwithstanding the fact that this is still a distortion of "natural" state of affairs (given the mined origins of this particular flux). This obviously has the potential benefit of substituting other forms of agricultural P inputs.

URBAN AGRICULTURE IN HARARE

According to UNDP, (1996) estimates, some 15% of food production in the world comes from urban agriculture (farming , horticulture, animal husbandry, fish ponds, etc.). Nearly 1 billion people are engaged in urban agriculture, 200 million producing food for markets. In cities such as Lusaka and Dar es Salaam as much as 50% is produced within the city. Given that half of the world population soon will live in urban areas, it could be expected that re-circulation of nutrients in urban areas will be featured high on the agenda in the near future. However despite many benefits, urban agriculture is an ill-understood industry.

Urban farming is often minimised as being merely "kitchen gardening" or marginalised as a leftover of rural habits. Certain myths still predominate e.g. urban agriculture means household and community gardening, urban agriculture is a temporary activity, urban agriculture is a marginal activity or means of survival, urban agriculture pre-empts "higher" land uses and cannot pay full land rent, urban agriculture competes with and is less efficient than rural farming, urban agriculture is unhygienic, urban agriculture causes pollution and damages the environment, urban agriculture is unsightly and aesthetically inappropriate in the city and the "garden city" is an archaic, utopian concept that cannot be created today (UNDP, 1996).

The history of urban agriculture in Harare is illustrated in Table 1. The problem of illegal cultivation of public land started as early as the 1950's and has gained momentum ever since. During the 1998-99 rainy season there has been a tremendous expansion of the area under cultivation. This can be attributed to general population increase, continued high rate of rural-urban migration, a growing number of dependants per household, burgeoning unemployment, and inflation resulting in a lowering of income in real terms.

Table 1 Extent of cultivated public land in Harare estimated from aerial photographs (1955-94).

Year of aerial photograph interpretation	**Area of public land (ha)**	**% of open space**
1955	270	1.0
1965	1070	4.0
1972	1400	5.5
1978	3700	14.0
1980	4760	18.5
1990	4820	19.0
1994	9290	36.0

Source: Bowyer-Bower *et al*., 1996

The cultivation of public space in Harare has largely been undertaken on vacant land adjacent to high-density housing areas. This land often comprises poorly drained vlei areas (67% of off-plot cultivated area) where soils are unsuitable for building. Roadside verges, land bordering railway tracks, and banks of ditches are also favoured. The cultivation is largely of crops for domestic consumption, mostly maize, groundnuts, sweet potatoes and green vegetables (Mbiba, 1995). Fig 2 shows the general land-use zones within the city of Harare and the location of vlei areas and public open spaces which are extensively cultivated. Vleis exist as seasonally waterlogged drainage ways. In Harare two main types occur: clay vleis developed on basic rock, which are mostly found in the northern half of Harare (largely the Gwebi, Umwindisi and the upper headwaters of the Marimba and Mukuvisi areas), and the sandy vleis occurring on granites, mostly on the southern half of Harare (major potions of the Mukuvisi) (Bowyer-Bower *et al*., 1996).

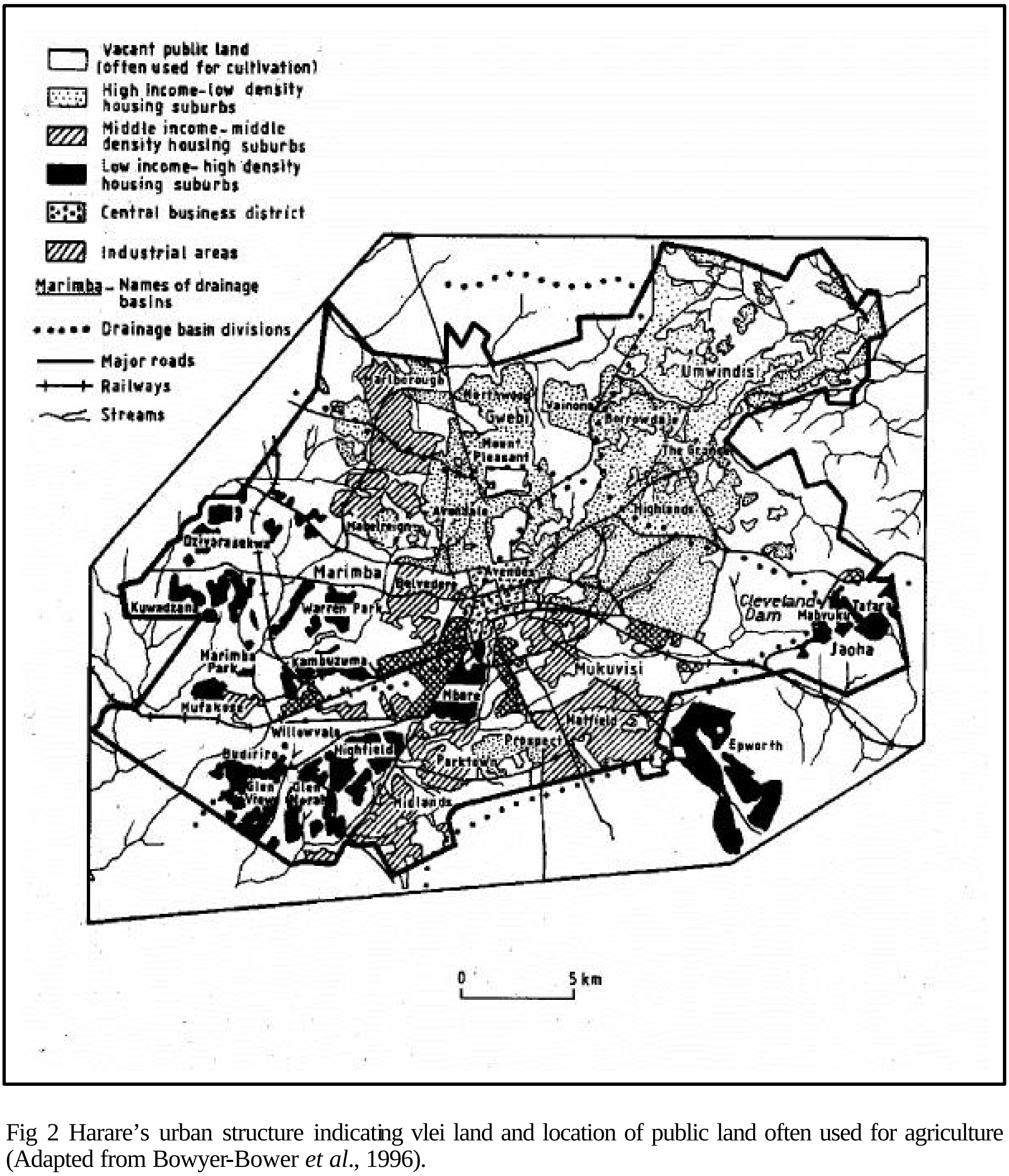


Fig 2 Harare's urban structure indicating vlei land and location of public land often used for agriculture (Adapted from Bowyer-Bower *et al*., 1996).

Bowyer-Bower *et al*., (1996) describe the effect of cultivation on the vegetation where a change of species composition (with natural vegetation being replaced by mainly alien arable weeds), the loss of spatial diversity in species presence and dominance, reduced ground cover and loss of habitat diversity. With more of the land surface exposed to the direct impact of rainfall and wind, it is expected that soil degradation (for example, an oxidation of organic matter content and a loss of soil structure), and soil loss by wind and water erosion, will occur. The agro-potential of the land will decline accordingly, and the vlei hydrology is also likely to alter. Serious potential effects include the choking of the vlei channels with sediment eroded from the vlei catchment areas as a result of cultivation.

In socio-spatial terms there are two main sources of urban food production, namely, the private space of urban gardens(on-plot i.e. within the pegged residential stand), and the public open spaces in and around the city proper (off-plot). In Harare the type of spaces include around buildings, community lands and parks, areas allocated to other uses, such as road verges and areas not suitable for building, such as flood plains, wetlands and steep slopes. Local Government reactions to urban food production (off-plot cultivation) have general been proscriptive, partly because it spoils the modern image that many administrators want for the city and partly because urban planning and management is not structured to incorporate such activities. Hostility and repression are, therefore, still far too frequent in Harare, despite the growing but reluctant toleration of urban agriculture which has followed recognition of increased pressures on the poor.

The City has recently formulated policies allowing urban agriculture (HCMP, 1992). This policy document tends to promote planned and organised urban agriculture. The enforcement of legislation, either through the destruction of crops or levying of fines, has been mollified in Harare to some extent by the opportunities for residents to form co-operatives and, as such, to apply for permission to use designated land for the cultivation of crops. The procedures for this are lengthy and cumbersome, and relatively few groups have, in fact, applied.

Urban agriculture in Harare is a challenge in both Management and research terms. Acknowledging its persistence, ubiquity, productivity and value to urban economies, heightens the need for research with a focus on Mbiba, (1995):

a) removing obstacles to urban agriculture and enhancing its stake in the urban economy.
b) how to promote urban agriculture without compromising on environmental quality and aesthetics in the urban areas.
c) urban food production and nutrition systems with special emphasis on the urban poor.
d) cost-benefit assessments of urban agriculture with special reference to opportunity cost of land utilisation.
e) integrating urban agriculture with health and waste management variables
f) access to land and equity issues in the production and distribution process with special reference to the gender dimension.
g) financing and control relationships on the activities at household and institutional levels (i.e. NGO's, government and community levels)
h) urban economy theories that recognize the importance of and incorporate urban agriculture in both its spatial, social and economic dimensions.
i) policy options that maximise benefits from urban agriculture without compromising on aesthetics, service provision and urban governance.

This research aims at integrating urban agriculture with urban waste management (point e and b in the text box) with a focus on the urban water cycle and possible diversion of human derived nutrients (excreta) to land for agricultural production. The basic approach employed is that of characterising P-fluxes and water fluxes in an urban-shed in Harare where urban agriculture is practised. It is perceived that this analysis will give insights into urban water cycle infrastructure design and hence sustainable recycling systems as opposed to the uni-directional conventional systems.

SETTING OF MICRO-STUDY CATCHMENT

The micro study catchment consisting of Mufakose and Marimba Park suburbs lie within a hydrological catchment area of 6.5 $(km)^2$ with a total population of about 100 000 (projected from 1992 census) which translates to a population density of about 7000 inhabitants/$(km)^2$.

The suburb of Mufakose was first constructed in the early 60's and expanded in sections until the early 90's. Mufakose and Marimba suburbs are situated in the western end of the city about 15 km from the city centre. Most of the residents in Mufakose are in the low-income band with an estimated income per household of about US $100 per month (PASS, 1995). The area consists of mainly semi-detached houses, a few flats, a few shopping centres, beer halls, places of assembly (churches), and schools. There are an estimated 9 600 residential stands including flats and about 100 non-residential stands in Mufakose. The average occupancy per stand is estimated to be 9.3 people. Marimba Park is an adjacent middle income housing area with about 500 fairly large residential stands of approximately 1 ha. The profile of the two suburbs is given in Table 2.

The area has its water supply coming from two main pipes with separate bulk meters and the average annual consumption recorded for the area is 2.4 Mm^3. The sewerage reticulation has two distinct out-fall sewers serving the area. The sanitation system is entirely water borne. A separate system for sewage and storm-water exists. However during rainy periods there is excessive infiltration of storm-water into the sanitary sewers causing overloading and surcharging of the network. The collection frequency of solid waste in the area is weekly. However field observations indicated that there is wide spread and indiscriminate dumping of solid waste due to the irregular collection frequency by the city authorities. The storm-water in the area is drained by a combination of piped, lined and unlined open channel. The storm-water network is poorly maintained resulting in clogging and blocking of catch-pits and drains. The storm-water is discharged untreated into Marimba River, and ends up in Lake Chivero, the city's main potable water source.

Much of the area is built up and almost all the remaining open spaces particularly near the edges are under cultivation yearly during the period November to March. Almost all of the properties are residential type with a few areas designated for commercial activities such as shops markets and other related business.

METHODOLOGY

Systems thinking and systems analysis

P-material and water flux analysis is conducted using systems analysis (list of educts/goods and products). Systems thinking advocate maintaining a bi-focal perspective. This means keeping one eye tuned to the biggest relevant picture while the other eye descends into the detail. This is an important approach when characterising and analysing material fluxes through the anthroposphere. Systems thinking involve drawing a boundary around a system in such a way as to cause what's inside the boundary to be the cause of the dynamics of interest. Further it picks up inside the boundary to say it is the stock and flow plumbing that is the cause of the dynamics. Lastly it says that the structural arrangements that bring the stock/flow plumbing into life are feedback loops.

STELLA Software developed by High Performance Systems (HPS) Inc. is used in this study as a modelling tool to enhance systems thinking and to generate insight into webs of interdependent relationships in the study of P and water fluxes. The model is still being developed. The use of STELLA enables the imbibing of the systems thinking paradigm and simplifies the handling of stocks/reservoirs, flows (input-output), infrastructures and feedback loops of nutrient fluxes within the micro study region. STELLA also enables the superimposition or combination of the water flux and the P-flux to create a model which can be adjusted accordingly to satisfy different boundary conditions. Socio-economic factors and cultural values (e.g. diet) can also be modelled.

Table 2 Profile of Mufakose and Marimba suburbs and the mirco-study catchment

Parameter	**Value**	**Remarks**
Population	100 000	Projected from 1992 census
Average household income Mufakose	US$100.00	Income per month (PASS, 1995)
Average household income Marimba Park	US$500.00	Income per month (PASS, 1995)
	9600	Semi-detached mostly, 150-200 m^2 in size (information from City of Harare Mufakose Housing Office)
Average floor area	50-70 m^2	
Number of residential stands in Marimba	500	Plot size ranges from 1000-2000 m^2
Average floor area	100-150 m^2	
Average occupancy per stand	9.3	For both suburbs
Average annual rainfall	820 mm/a	Long term average measured at Belvedere Meteorological Station within greater Harare
Average annual Evaporation	1500 mm/a	Long term average measured at Belvedere
Total annual water consumption	2.4 Mm^3/a	As recorded from bulk meter readings (records kept by City of Harare Mufakose Housing Office)
Breakdown of water usage per household Bathing Kitchen and other culinary functions Laundry Toilet flushing (WC) On-plot garden watering	 25% 10% 15% 30% 20%	The figures were established through a survey. For toilet flushing the average cistern size is 15 litres. A significant volume of water is used for on-plot vegetable production.
Size of area	6.5 $(km)^2$	System/Hydrological boundary (calculated from topographical map)
Total impervious area	2.1 $(km)^2$	Estimated at about 32% of the total area from aerial photographs taken in 1997 and the street map of Greater Harare.
Impervious area consists of: Streets (surfaced and un-surfaced) Off-street impervious area Roofs	 15% 2% 15%	Off-street impervious area comprises of pavements and surfaced areas within plots. A large percentage of the rain water fa lling on roofs ends up in the foul sewerage system
Total pervious area	4.4 $(km)^2$	About 68% of the total area
Pervious area consists of: On-plot garden area Open public spaces	 0.8 $(km)^2$ 3.6 $(km)^2$	Open space is undeveloped or reserved for future developme nt, it also consists of vleis, road reserves and stream-banks. About 60% of this area is under cultivation illegally or legally.
Total area under cultivation	2.9 $(km)^2$	Both on-plot and off-plot, illegal and illegal

In this study 3 subsystems have been identified in order to simplify the analysis, namely;

1. Agriculture: Soil-Plant interaction subsystem
2. Household: Consumption-use and excretion by humans
3. Urban water cycle: Conventional system

On spatial terms the boundary conditions are on a human being (man), then household and agriculture all within the regional boundary (neighbourhood). The region can be further enclosed in a larger boundary which can be defined as desired (Fig 3). For example the Mufakose Marimba Park area can be taken to fall within the Greater Harare area or within the Marimba River basin. There are interactions between each boundary and among the subsystems.

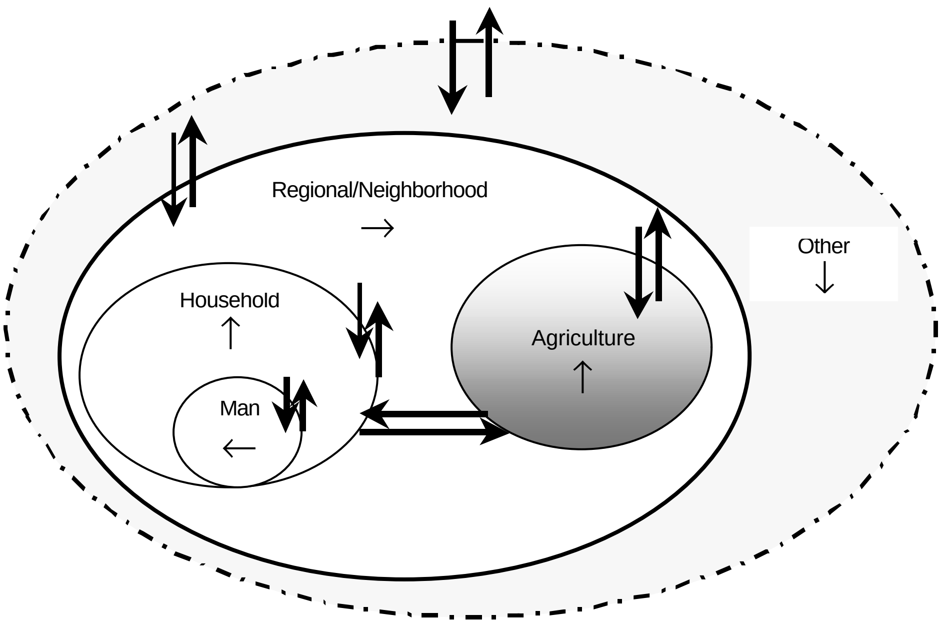


Fig 3 Framework for setting boundaries for analysis within systems thinking. The numbers illustrate the increase in spatial terms of the different boundaries.

Material flow analysis (MFA)

Sustainable development is a stewardship concept. It is the idea that we bear a responsibility for the legacy, which we leave to future generations. This legacy can, in broad terms, be thought of as having environmental, economic and social components. Progress towards sustainability will depend on the reduction of resource input on the one hand and the further reduction of pollutant output on the other hand. Material flows through the anthroposphere connect both of these ends but the flows are handled by different actors and cross several sectors. For instance, mineral fertiliser may stem from mining and go to transport, agriculture, food industry, super markets, households, sewage treatment plants, in order to end up in rivers and finally the sea. On this way they are part of different products and their flow is intermingled with other flows of substances, bulk materials and water. Sustainable materials management will involve the different actors in an integrated manner.

The tracking of the flow of materials and products though society and the environment is an activity of increasing prominence and consequence throughout the world. Material Flow Accounting (MFA) is the investigation of the physical flows of materials, typically on a geographic basis. MFA can help us understand how changes in land use, industrialisation, consumption and population affect the cycles of chemicals of concern in a watershed. It provides a means of taking a comprehensive rather than an ad hoc view of the drivers and source of substances.

In order to follow certain goods or elements, the processes, import, transformation, transport, storage, and export have to be analysed. Material fluxes are characterised by parameters of the natural sciences, primarily physical and chemical. It is evident that socio-economic characterisation is indispensable for understanding the mechanisms of material transport within the anthroposphere. A question, which also arises, is that of the residence times of materials and the build up of stocks within the anthroposphere. For example the compartment "household" acquires goods (flux "sale") and releases them (flux "waste") after consumption. These goods have different residence times within this compartment (reservoir "stock") during "consumption". In terms of systems theory, an efficient feedback mechanism has to be developed for the metabolism of the anthroposphere, between the geogenic and anthropogenic networks within a regional economy.

P AND WATER FLUX BALANCE IN STUDY AREA

The three subsystems defined in the previous section are considered in turn and values from literature and records kept by various institutions in Harare a first estimate of the different fluxes and storages can be made.

Subsystem 1 Agriculture: Soil-Plant interaction

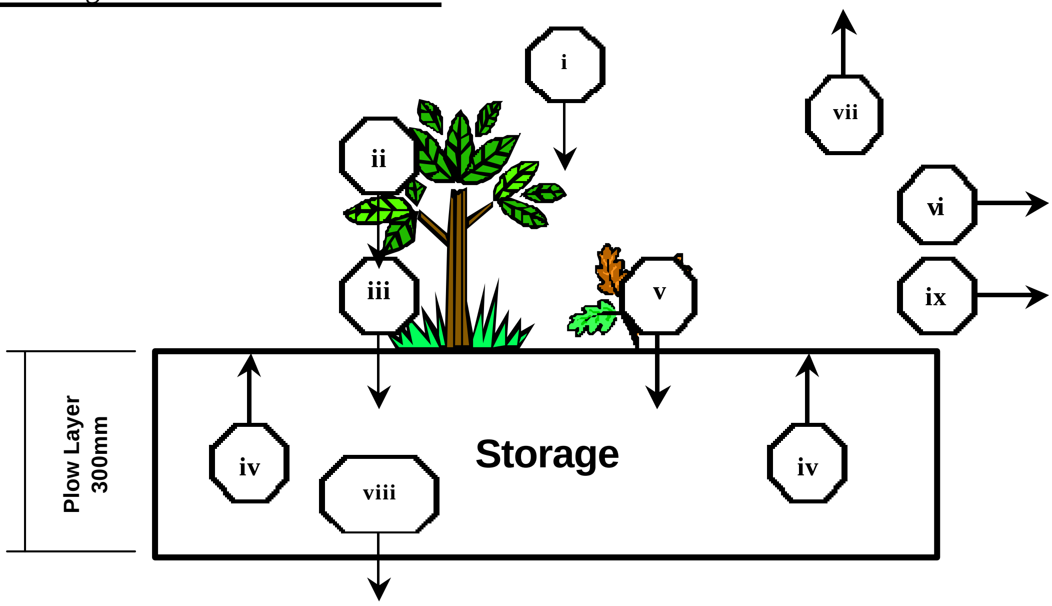


Fig 5 Schematic representation of subsystem 1

Table 3 lists the different fluxes and storage for this subsystem and provides corresponding values, which apply to the study micro-catchment.

Subsystem 2 Household: Consumption-use and excretion by humans

The two main activities being focused on with regard to P-bearing materials and connected to household activities are namely; to nourish and to clean. To nourish comprises all processes and goods to produce solid and liquid food for man and to clean comprises all processes to maintain human health and to provide environmental protection from pollution (Baccini & Brunner, 1991). Without any comprehensive data for Harare and within the micro-study catchment a major part of the research will be to study the urban food supply and demand system in this area. The urban food system consists of the food that residents consume the places where it is produced and the often-complex process by which it gets from producers to consumers.

Table 3 P flux balance and storage for the agriculture subsystem

Flux	Value	Reference	Remarks
(i) Atmospheric fallout i.e. wet and dry deposition	0.2-0.5 kg/ha.a say 0.3 kg/ha.a	White, (1979)	P-concentration in the atmosphere deposited mainly on the lithosphere by rain are usually low. This depends on P load to the atmosphere.
(ii) Mineral fertiliser application	Assuming the application rates are half the prescribed value say 30 kg/ha.a	Mbiba, (1995); ENDA-Zimbabwe, (1996); Nyamangara & Mzezwa, (1996); Tiessen, (1995)	For optimal maize production in Zimbabwe 400 kg/ha of compound D fertiliser is recommended (Compound D 8% N; 14% P_2O_5; 7% K_2O and 6.5% S. 80% of the croppers in Harare use chemical fertilisers.
(iii) Manure applications	say 1.0 kg/ha.a	Mbiba, (1995); ENDA-Zimbabwe, (1996)	60% of the cultivators use imported organic manure on gardens in the form of sawdust, mulch, compost and tobacco. P-content of these materials is generally regarded to be very low
(iv) Crop/Plant/ vegetation uptake	say 20 kg/ha.a	White, (1979); Baccini & Brunner (1991)	80% of the cropping is maize for a yield of 4000 kg/ha.a P uptake is estimated at 35 kg/ha. Sweet potatoes and groundnuts have a lower P-uptake. A yield of 2000 kg/ha.a is assumed
(v) Harvest residue/vegetal die-off	say 5 kg/ha.a	Mbiba, (1995); ENDA-Zimbabwe, (1996)	About 14% of the maize stocks are burnt, 5% contributes to the solid waste and the remainder is used as pit or surface compost. The contribution from natural vegetation, leaf fall etc
(vi) Harvest (vii) Burning residue and atmospheric loading	say 7kg/ha.a say 1.0 kg/ha.a	Tiessen, (1995)	P-content of harvested portion of crop commodities (based on market weight) for cereals i.e. including maize is 3.3 mg/g. Assuming a yield of 2000 kg/ha.a No figures available, however slash and burn is extensively practiced during preparation of the fields before the onset of the rains
(viii) Leaching	say 1.0 kg/ha.a	Tiessen, (1995); White, (1979)	Very low, with the exception of very sandy soils. Urban Agriculture in Harare mainly occurs on vleis, clay and sandy vleis. Usually less than 1kg/ha.a
(ix) Runoff/wash out	say 8kg/ha.a	Tiessen, (1995); Stocking (1986)	Dependent on arable land cover, slope, stream network density and rainfall (amount of sediment in runoff). 90% of P transport linked to erosion, range 0.1 to 10 kg/ha.a in Zimbabwe its estimated at 8 kg/ha.a
Storage	Say 800 kg/ha	White, (1979); Tiessen, (1995); Grant, (1981)	90% of total P is contained in the top 30 cm of soil (Plow layer) and the P content within this layer varies from 100 to 3000 mg/kg. Most Zimbabwean soils (tropical soils in general) are deficient in N, P, S and Ca. P-content in soils ranges from 500-2500 kg/ha

In Harare there is some literature on food and the urban poor but it covers only patches of what most geographers would see as a complex and interrelated network of social, economic and political phenomena (Drakakis-Smith, 1992). There has been far less written about the urban food supply systems than other basis needs, particularly shelter, despite the fact that food is the most basic of needs and that shortages are a more likely cause of urban instability than inadequate provision of housing or education.

Detergents with tri-phosphates and poly-phosphates are also the main P-imports into the system. JICA, 1996 established that the unit pollution load in Harare measured, as Total Phosphorus (TP) was in the range of 1.3 to 1.4 g/capita/day as compared to an average of 1.2 g/capita/day for Japan. The high TP values for Harare were attributed to use of detergents containing phosphates. Table 4 lists the various fluxes and storage for the household subsystem and some values gathered from literature are presented.

Table 4 P flux balance and storage for the household subsystem

Flux	Values	Source	Remarks
(i) Food /Nourishment	Dependent on diet	Mbiba, (1995); Baccini & Brunner (1991)	In Mufakose, sadza and relish (leafy vegetable) are the two most consumed food items. An average family size of six consumes 360 kg/a of mealie meal, no figures are available for other food stuffs
(ii) Detergents / soap and other products	No figures available	Baccini & Brunner (1991)	In the goods detergent a tri-phosphate is used as a chelating agent to prevent calcium precipitation
(iii) Food residues/Solid waste	No figures available	Hakan, (1999)	For a Swedish community 21% of P-content of food stuffs ends up in solid organic waste (household level), 65% in urine and faeces, 4 % waste from trade (market) and 10% in industrial and restaurant waste (processing). Accumulation of P in body mass is negligible for adults (> 12 years)
(iv) Greywater flux	No figures available	Olson, (1968)	Approximately 0.15 g/pd excluding detergents. For Sweden, average including detergents is 3.1 g/pd
(v) Urine / Yellow water flux	0.5 kg/a or 1.2 g/pd	Hakan, (1999); Larsen & Gujer (1996)	95-100% phosphate ions (primary, secondary and pyrophosphate. Urine contains 50-80% of P intake. For 2-12 age group a 80% excretion rate of the adults can be assumed. Same excretion rate for diet containing meat and vegetarian
(vi) Faeces/Black water flux	0.2 kg/a or 0.5 g/pd	Hakan, (1999); Larsen & Gujer (1996)	Major portion as calcium phosphate, organic substances, and little phosphate ions.
(vii) Stormwater flux or Runoff/washout	No figures available		
Storage			Considered to be insignificant as normally all the P containing commodities are consumed within a week or a few days.

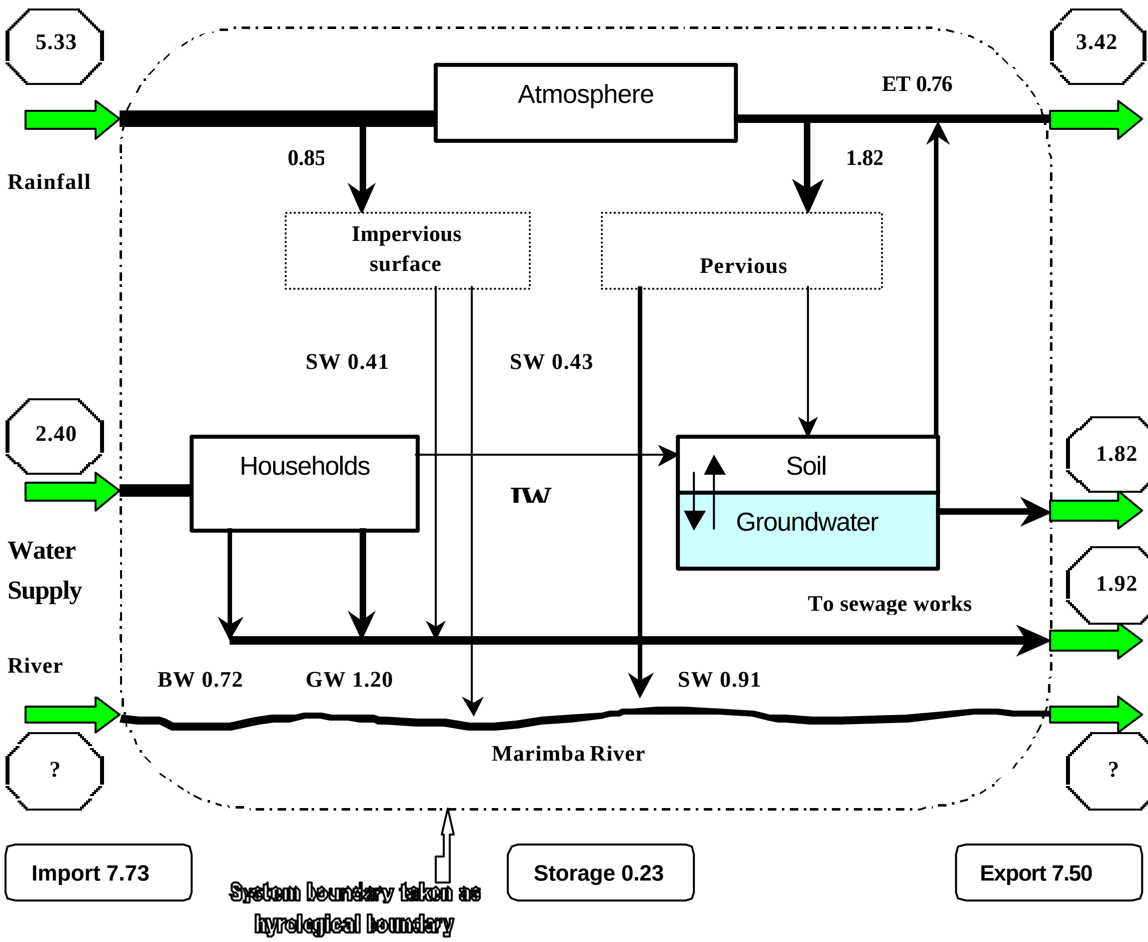
Subsystem 3 Urban water cycle: Conventional system

The components or fluxes for this systems are as listed below

(i) Rainfall
(ii) Mains water supply
(iii) Evaporation = (Interception + Transpiration + Dry soil evaporation + Evaporation from open surfaces)

(iv) Infiltration
(v) Deep aquifer recharge
(vi) Ground water flow
(vii) Storm-runoff
(viii) Grey water
(ix) Black water
(x) Storage (Soil moisture + Groundwater + Surface storage)

Since the transport and transformation of P in a region is dependant on the water cycle, investigations of the flux of water as precipitation, (white water), surface water (blue water) and ground water (deep blue water), soil moisture (green water), piped potable water, and wastewater (in the form of storm, grey and black water), forms an integral part of this study. Using the figures in Table 2 and through estimation, an annual water flux balance for the system can be established (Fig 6). The system consists of 4 processes (solid rectangles), 3 import fluxes and 4 export fluxes. Overall 7.73 Mm^3 of water are imported per year (assuming ground water import is zero), 7.5 Mm^3 is exported and 0.23 Mm^3 is stored within the micro-catchment. The flux between soil and the groundwater is an estimate based on the soils and geological formations typical within the Harare area. The amount of water exported as sewage is a significant percentage (26%) and more than 60% of this flux is derived from the activity to do with cleaning (bathing, toilet flushing, laundry, dish washing i.e. grey and black water). The role of soil and its vegetation in relation to bio-mass production in the area is difficult to estimate (green water) and similarly the evapo-transpiration (white water).



Key: BW = Black Water
GW = Grey Water
IW = Irrigation Water
SW = Storm Water
ET = Evapo-transpiration
N.B. The flow of surface water into the boundary area through Marimba river was not estimated.

Fig 6 The average annual water flux balance for Mufakose and Marimba Park (All figures in Mm^3/annum).

CONCLUSIONS

The need for P is expected to increase both in agriculture and industry, and more than ever, short-cutting P-cycles will become necessary, not only to prevent nutrient enrichment of rivers and lakes, but also to lengthen the availability of a finite resource. The ultimate aim of this research is to create a model which represents, on an annual basis, water and P-fluxes (including storage) into and through an urban-shed.

With this tool quantitative P-fluxes though the hydrosphere of some micro regions can be evaluated and options of recovery, recycling or diversion of P in a beneficial manner i.e. through the adoption of urban agriculture can be investigated. The water flux and the P-flux have to be carefully analysed so that in advocating for a different UDS one could at least foresee the probable consequences within reasonable limits. It is however clear that better nutrient management will also mean dramatic changes in the way the sewage pipe system in particular is built and used.

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REFERENCES

Ausubel J.H., (1992), “Industrial Ecology: Reflections on a Colloquium”, Proc. National Academy of Sciences USA, 89, pp 879-884.

Baccini P., and Brunner P.H., (1991), Metabolism of the anthroposhpere, Springer-Verlag, Berlin Heildelburg.

Beck M.B., Chen J., Saul A.J., and Butler D., (1994), Urban drainage in the 21st Century: Assessment of new technology on the basis of global material flows, Wat. Sci. Tech., 30, (2), 1-12.

Bowyer-Bower T.A.S., Mapure I., and Drummond R.B., (1996), Ecological degradation in cities: Impact of urban agriculture in Harare, Zimbabwe, Journal of Applied Science in Southern Africa (JASSA), The journal of the university of Zimbabwe, Vol. 2, No. 2, pp53-67.

Butler D., and Parkinson J., (1997), Towards sustainable urban drainage, Wat. Sci. Tech., 35, (9), 53-63.

CEEP & CEFIC, (1997), Centre Europeen d’ Etudes des Polyphophates, A sector group of the European Chemical Industry Company (CEFIC), The Phosphate File : An overview of industrial phosphates.

Drakakis-Smith D.W., (1992), “Strategies for meeting basic food needs in Harare”, in Baker J. and Pederson P.O. (eds), The rural-urban interface in Africa (Nordiska Afrikainstitutet, Uppsala), pp258-283.

ENDA-Zimbabwe, (1996), Urban agriculture in Zimbabwe, Results and recommendations of a household survey conducted in Harare, Research, Development and consulting Division (REDEC), and Environment and development Activities (ENDA), Zimbabwe.

Esrey S.A., (1998), Rethinking Sanitation: Panacea or Pandora’s Box, WHO International Conference on Water, Sanitation, and Health: Resolving conflicts between drinking water demands and pressures from society’s wastes, Bad Elster, Germany.

Grant P.M., (1981), The fertilisation of sandy soils in peasant agriculture, Zimbabwe Agricultural Journal, 78, 169-175

Hakan J., (1999), The nutrient cycle and the urban society, unpublished lecture notes, Uppsala Agricultural University, Sweden.

HCMP, (1992), Harare Combination Master Plan, Report, City of Harare Zimbabwe.

JICA Report, (1996), The study on Water Pollution Control in Upper Manyame River Basin in the Republic of Zimbabwe, MLGRUD, Nippon Jogesuido Sekkei Co. Ltd., Nippon Koei Co. Ltd., July.

JICA Report, (1996), The study on Water Pollution Control in Upper Manyame River Basin in the Republic of Zimbabwe, MLGRUD, Nippon Jogesuido Sekkei Co. Ltd., Nippon Koei Co. Ltd., July.

Larsen T.A., and Gujer W., (1997), The concept of sustainable urban water management, Wat. Sci. Tech., 35, (9), 3-10.

Mbiba B., (1995), Urban agriculture in Zimbabwe, Implication for urban management and poverty, Avebury.

Nymangara J. and Mzezwa J., (1996), Maize growth and nutrient uptake in Zimbabwean red clay soil amended with anaerobically digested sewage sludge, Journal of Applied Science in Southern Africa (JASSA), The journal of the university of Zimbabwe, Vol. 2, No. 2, pp83-89.

Olson E., (1968), Residential Wastewater. The Swedish Nation Institute for Building Research, Sweden.

PASS, (1995), Poverty Assessment Study Survey report, Ministry of Public Service Labour and Social Welfare, Government of the Republic of Zimbabwe, Harare, Zimbabwe.

Stocking M., (1986), The cost of soil erosion in zimbabwe in terms of the loss of three major nutrients. Consultants working paper No. 3, Soil Conservation Programme, Land and Water Development Division, FAO, Rome.

Tiessen H. (Ed.), (1995), Phosphorus in the global environment; Transfers, cycles and management, SCOPE 54, John Wiley and Sons.

UNDP, (1996), Urban agriculture. Food, jobs and sustainable cities, UNDP Publication Series for Habitat II, Volume 1, New York.

White R.E., (1979) Introduction to the principles and practice of soil science, Blackwell scientific Publications.