A holistic approach in the analysis of and turn-around strategies for municipal water supply systems – The perspectives of a financier

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Background

As South Africans are becoming more aware of the scarcity of water and the risk that water shortages pose for all of us, there is renewed focus on the current state of municipal water supply systems. This focus is long overdue as for many years municipal supply systems have been operated and maintained inefficiently with little focus (and spending) on critical issues such as maintaining the integrity of the infrastructure, managing demand and adequate cost recovery. In many instances, throughout the value chain, systems have been poorly designed, not properly implemented and are in a poor state of repair and operation. This has led to a steady decline in customer service levels and reliability of supply countered by ever increasing water losses. The situation has reached critical proportions in many districts as losses have increased to such an extent that supply to consumers are failing and existing resources can no longer meet the required supply.

From a financial perspective the impact on municipalities has been significant. What should have been a service running at a healthy surplus and boosting municipal funds to be deployed on other services has become a financial drain for most municipalities. This has contributed largely to most municipalities struggling to remain financially viable and sustainable. If the political will to address this situation was lacking in the past, recent protest action over poor and unreliable service delivery (often relating specifically to water supply) as well as some high profile regional breakdowns that impacted large consumer populations are hopefully changing this.

More importantly, there is growing realisation that development of new water resources to supply the current and growing demand will be: (i) expensive and (ii) not sustainable, given the status quo. Simply put, it may be cheaper and make more economic sense to revamp existing systems to eliminate water losses and to reduce demand. The problem is that often this is viewed as a simple process of replacing old pipes with new pipes. But, achieving a sustainable water supply business that is financially viable and economically optimised is much more complex than replacing old pipes. Added to that is the fact that the quantum of investment required to address the situation is of such a magnitude that it lies outside the normal capital expenditure budget range of most municipalities. An obvious solution is for municipalities to secure external finance for these works, but the credit and risk evaluation requirements of financiers go way beyond a simple plan to replace pipes.

Existing methods used by municipalities to identify projects of this nature are typically one-dimensional and lacking in adequate risk assessment. A new, more holistic approach, through which key risks are managed, is required with the main purpose to enable granting of finance for these projects.

Current Analysis Approach

To put the need for a new approach in context it is best to start with current practice of analysing a municipal water supply system. Figure 1 below illustrates the ‘Best Practice’ Water Balance as published by the International Water Association (“IWA”).

<table>
<tr><td rowspan="9">System Input Volume (corrected for known errors</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer metering</td></tr>
</table>

Figure 1: Best Practice Water Balance.

This water balance identifies different components that make-up the total demand for water as measured at the input of a water supply system. Most of these components are self-explanatory and each one of them can be analysed to identify specific issues in the water supply value chain of a municipality. For example the ratio of Revenue Water/System Input Volume can be used as a simple indicator of the sustainability of the operation. Clearly, a low ratio indicates an operation that is not sustainable – unfortunately the status quo in most municipalities. This water balance figure is useful to highlight specific issues and to formulate simple strategies to enhance the (financial) viability of a supply system. For example, it is easy to identify the elimination of Metering Inaccuracies as a specific strategy to reduce Water Losses or the conversion of Unbilled Authorised Consumption to Billed Authorised Consumption to increase Revenue Water. During the past decade, the IWA, has significantly progressed the application of and body of knowledge around the Water Balance through specific research and publications.

A key problem is that most of these sub-components are not readily quantifiable. As an example, to determine the extent of Real Losses in the system requires careful design of the reticulation network and an extensive metering system on top of it – something that does not exist in most locations in this country.

The dilemma that a municipality faces is this: how to evaluate a project to reduce the Real Losses and motivate the required capital investment if the quantum of the Real Losses is unknown or at the very least highly uncertain? This dilemma is multi-faceted and includes the following issues:

- How is the project to reduce Real Losses formulated?
- How is the required capital estimated at an adequate level of confidence, given that the quantum of Real Losses is at the very least highly uncertain? and
- How is the required capital investment motivated given the high level of uncertainty (around the payback) and the already strained financial position of the municipality?

Addressing, this dilemma is a key focus area and is explored further in this article.

Various methods to estimate the Real Losses have been developed over the years - monitoring of night flows and flows under reduced pressure are examples. However, in this context one should differentiate between identification of the presence of Real Losses versus the quantification thereof. For example, monitoring of night flows (on a continuous basis) in an area can quickly indicate the presence of new leaks which can then be fixed – this would be part of the on-going maintenance function. At some point in time however, the frequency of new leaks etc. would indicate the need for overall replacement of the distribution/reticulation system. At this point in time the need to quantify Real Losses would arise, as it would play a critical role in the capital investment decision.

There is one further issue with regard to the reduction of Real Losses that is worth discussing briefly. It is fairly obvious and widely understood that no system can operate at zero Real Losses. The critical question is: what level of Real Losses is acceptable? Until recently this level was internationally, loosely agreed at 15%. It is however clear that a uniform figure cannot apply to every system and that the 'law of diminishing returns' applies to the reduction of Real Losses. The absence of an extensive metering system through which Real Losses can be quantified and located makes it impossible to analyse the impact of the 'law of diminishing returns' and exacerbates the dilemma of municipalities outlined above. In response to this the IWA has developed the concept of Unavoidable Annual Real Losses (in this article we will simple refer to Unavoidable Real Losses ("URL")) and more importantly a methodology for estimating URL – this estimation depends on a number of parameters such as total length of pipeline, number of connections, operating pressure etc. Although it is not based on financial or economic analysis (as would typically be the case to illustrate diminishing returns) it does at least move away from the 'one size fits all approach'. Based on this development the Real Losses in a system can be split into two components: the URL and Recoverable Real Losses. From a financing perspective, it is held that only capital invested to eliminate the Recoverable Real Losses can be motivated.

But the problem of achieving a sustainable (and bankable) system goes further than eliminating the Recoverable Real Losses. There are critical factors in play that are not immediately evident from the Water Balance reflected in Figure 1. It is the view of the authors that unfortunately in our municipal sector the focus has been isolated on Real Losses at the expense of ignoring these critical parameters. For example, when looking at the Water Balance the impression may be gained that the component Revenue Water translates directly into revenue for a municipality and that through maximising this component the revenue of the municipality will be maximised. That is not true! The process of converting Revenue Water to revenue is a risky process. The significant amounts of debt that municipalities write off every year attests to this fact.

It is critical that 'Recovery Risk' be assessed and adequately factored into a project. To achieve this, the Water Supply System must be designed to minimise this risk and it is clear that the pricing -, metering-, billing -, accounting - and collection functions are part of this Water Supply System. To understand this risk better, the consumer base can be evaluated and the Revenue Water can be divided into the components as shown in Figure 2 below.

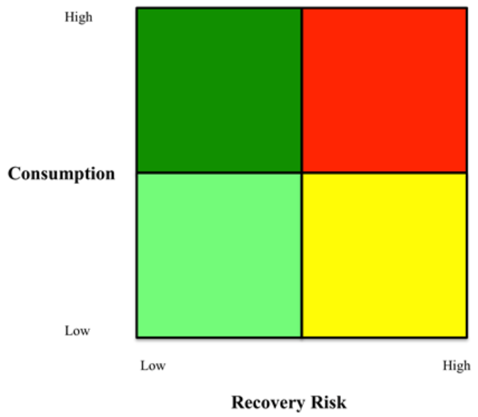

Figure 2: Consumer base analysis.

The impact of the four components reflected above on the actual revenue of a municipality will differ significantly. Clearly, the two components with the shades of green (the 'Low Recovery Risk' portion) are beneficial (from a financial perspective) to the municipality. Traditionally, Recovery Risk is a function of the social – and financial profiles of consumers served as well as historical cost recovery data.

It is easy to see that in general different water supply strategies, - systems, - service levels and recovery strategies should be applied to all four components above. This is especially true where a specific component dominates a geographical area or supply district/zone. In practice, different strategies are seldom applied or implemented. It is also clear that capital expenditure that will rely on revenue collected from the 'High Recovery Risk' components will be more difficult to motivate for finance.

Another critical factor in play revolves around the economic phenomenon of 'price elasticity of demand' – which dictates that as the price of a commodity declines demand/consumption will increase and vice versa. Water is a (scarce!) commodity and does experience some degree of price elasticity of demand. To illustrate the impact of this further we define the concept of 'Economic Cost of Water' (R/kl) as that cost that fully provides for all system input costs, system operating and maintenance costs, billing and collection costs, cost of capital as well as a charge for risk. A typical price elasticity of demand curve is illustrated in Figure 3 below.

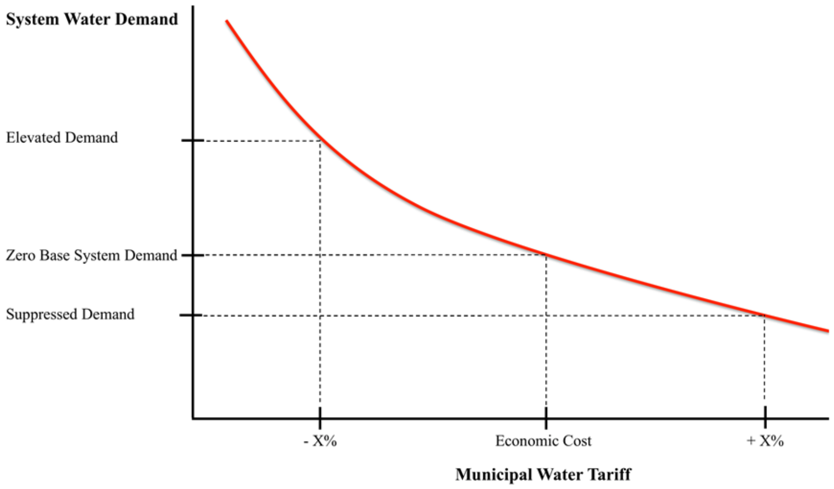

Figure 3: Price elasticity of demand.

This figure highlights three key parameters:

- Zero Base System Demand: the demand for water that will result in the system if water is priced at the Economic Cost and there is no other restriction on consumption (such as supply constraints etc.).
- Elevated Demand: the demand for water that will result in the system if water is priced below the Economic Cost and there is no other restriction on consumption (such as supply constraints etc.).
- Suppressed Demand: the demand for water that will result in the system if water is priced above the Economic Cost or there are other restrictions on consumption (such as supply constraints etc.).

The difference between Elevated Demand and Zero Base System Demand is labelled 'Over Consumption' for simplicity. It is proposed that Over Consumption is widespread and significant in many municipalities in South Africa for the following reasons:

- Many municipalities have not correctly determined their Economic Cost and have set water tariffs (significantly) below this critical level.
- The widespread occurrence of unmetered, unbilled supply – which effectively sets the price at zero.
- The widespread occurrence of metered, unbilled supply - which also effectively sets the price at zero.

In itself, Over Consumption is not necessarily a bad thing – depending on the operating leverage the increased consumption may compensate for the increased cost. There are two situations however where Over Consumption is financially debilitating for municipalities and is critical to eliminate ~

- When Over Consumption occurs in the High Recovery Risk portion of the consumer base.
- When new water resources have to be developed (at great cost) to meet growing demand.

Both these situations are prevalent in many municipalities and highlight the critical nature of Over Consumption.

An Alternative More Holistic Approach

The discussion above leads us directly to an alternative, more holistic perspective of the water balance, which is presented in Figure 4 below.

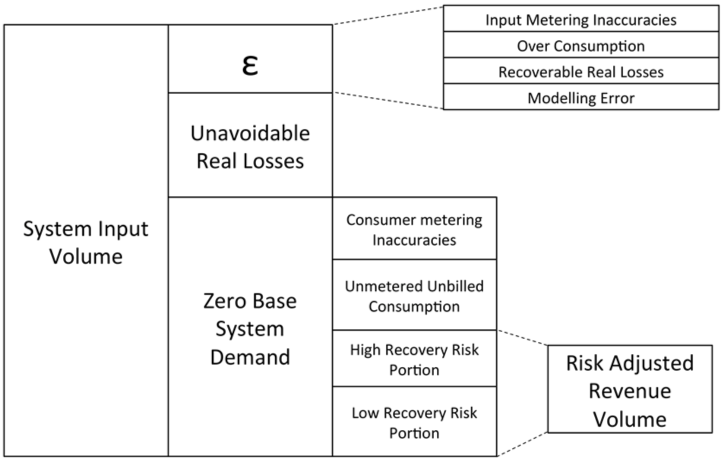

Figure 4: Alternative Perspective of the Water Balance.

Zero Base System Demand: as discussed above, this is the system demand that will result if water is priced at the Economic Cost and there is no other restriction on consumption (such as supply constraints etc.). There are various methods and models through which this important parameter can be estimated. Of key importance is that this remains an estimate and any model used should preferably be based on reliable statistical analysis that will provide quantitative information on the uncertainty in the estimate. This uncertainty represents 'Demand Risk' - one of the key risks in the water value chain of a municipality and it is critical from a financing perspective that this risk must be adequately mitigated. Zero Base System Demand is thus a statistical variable with an associated probability distribution as illustrated from an actual case-study in Figure 5 below.

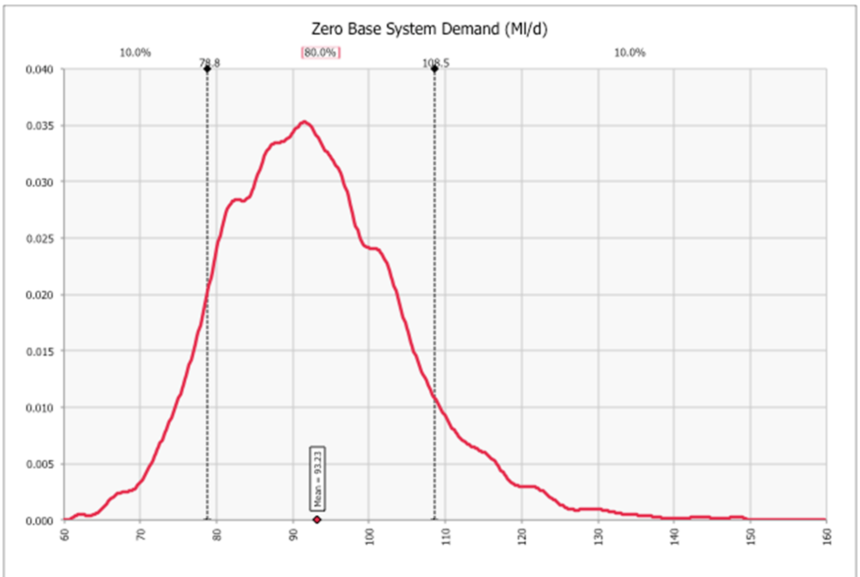

Figure 5: Example of the probability distribution of zero based system demand.

The probability distribution reflected in Figure 5 has a mean of 93.2 Ml/day – this means there is 50% likelihood that the true demand is less than this value and 50% likelihood that the true demand is greater than this value. From Figure 5 it is also clear that there is 80% certainty that the true demand lies in the range 78.8 to 108.5 Ml/day. This range is a direct measure of the 'Demand Risk' of the relevant system although in practice the variance of the distribution would be used for this purpose. In the absence of a complete and accurate measurement system this distribution represents the best estimate of the true system demand. Given the particular distribution, it is clear that ignoring ‘Demand Risk’ in any analysis of the system would be perilous.

Unavoidable Real Losses: is estimated as per the guidelines of the IWA. Due to the uncertainties around different parameters that are likely to exist in any system, this parameter should also be a statistical variable with an associated probability distribution.

ε: is a difference parameter that is obtained by subtracting the aggregate Zero Base System Demand and the aggregate Unavoidable Real Losses from the aggregate System Input Volume for a given time period. It is proposed that this time period should not be less than 6 months and preferably at least 12 months. The parameter ε will also be a statistical variable with an associated probability distribution as illustrated in Figure 6 below.

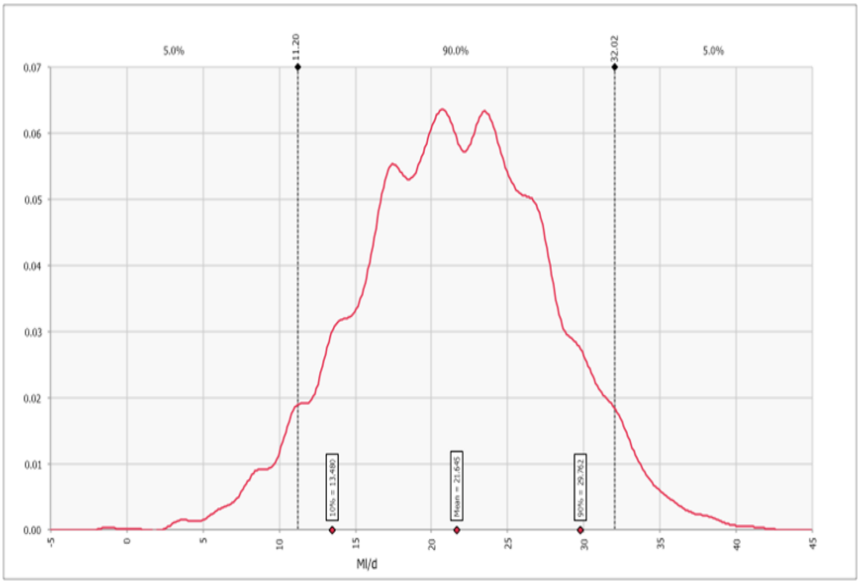

Figure 6: Example of probability distribution of ε.

The wideness of the distribution of ε in the example above indicates just how uncertain this variable is and how risky it would be to base any calculations etc. on a single value.

In the alternative perspective presented in Figure 4, ε is the aggregate of four different statistical variables:

- Input Metering Inaccuracies – these are metering inaccuracies in the measurement of the System Input Volume only (other metering inaccuracies are not in play here). As such, this will typically represent a relative small number of meters that need to be calibrated in order to eliminate the impact of this parameter.
- Over Consumption – as discussed above, Over Consumption may be present in the system due to specific features of the system. Other than such qualitative indicators as to its likely presence, Over Consumption can only be quantified if consumption of all consumers in a system is measured. This is highly unlikely except for relatively small systems.
- Recoverable Real Losses – these are physical losses in the system that can (and should) be eliminated through a suitable leak detection and repair programme.
- Modelling Error – this parameter represents any differences between the statistical model of the consumer population, used to calculate the Zero Base System Demand and the ‘true’ consumption of the consumer population.

If the Input Metering Inaccuracies are eliminated as proposed above and it is assumed (for the moment) that the Modelling Error is relatively small, then the probability distribution of the parameter ε represents an upper bound for the probability distribution of the sum of Over Consumption and Recoverable Real Losses. In the absence of extensive metering and other analysis that will allow these two variables to be quantified or specific loss situations that are known and clearly manifest (such as a distribution pipeline reaching the end of its useful life) they should be treated as inseparable. At best, in situations where there is reasonable certainty that none of the factors that would typically indicate the presence of Over Consumption as discussed above are present, it may be assumed that Over Consumption is relatively insignificant. This implies that the formulation of any water conservation project must aim to address both these parameters and this highlights the risk of focussing on elimination of Real Losses in isolation.

The alternative perspective of the Water Balance in Figure 4 assists to identify two generic types of projects:

- Conservation Projects: these projects will aim to reduce the System Input Volume through a reduction in the risk variable ε.
- Demand Side Projects: these projects will aim to supply the (current and future) Zero Base System Demand through an increase in the risk variable Risk Adjusted Revenue Volume.

The capital investment for any Conservation project will be motivated through:

- The potential cost savings through a reduction in the System Input Volume – typically only variable costs will be saved. The probability distribution of the parameter ε represents the risk that this saving will materialise and will thus enable robust risk analysis of the proposed investment.
- The financial benefit that will result if capital expenditure on development of new water resources can be delayed for any length of time due to the reduction in the System Input Volume. This represents a real option for the municipality that can readily be priced with the information available.

The capital investment for any Demand Side project must be motivated through an appropriate increase in the Risk Adjusted Revenue Volume and the associated increase in revenue to the municipality. It is important to note that the ratio of the Risk Adjusted Revenue Volume/Zero Base System Demand represents the true performance of the municipality from a recovery perspective (the 'Recovery Ratio') – a parameter that is seldom calculated nor reported accurately by municipalities.

Any turn-around programme to re-establish the sustainability and financial viability of the water business of a municipality must focus on the maximisation of the Risk Adjusted Revenue Volume as a priority – thus Demand Side projects. From this perspective it is critical to:

1. Understand the geographical distribution of the High Recovery Risk consumer population and the Low Recovery Risk consumer population.
2. Formulate separate strategies for the supply to and recovery from these consumer population groups with a specific view to mitigate Recovery Risk and minimise Over Consumption in High Recovery Risk areas.
3. Adjust the overall system design to implement the strategies formulated in 2 above.
4. Maintain the Recovery Ratio of the municipality above a suitable and appropriate threshold.

Municipal Tariffs

The importance of setting the water tariff of a municipality to at least equal the Economic Cost is clear from the discussions above. There are specific issues with regard to the determination of the Economic Cost (and thus the appropriate tariff) that is evident from the alternative perspective of the Water Balance as per Figure 4 that warrants further discussion. In the first instance, great care should be taken to ensure that the full cost of the Unavoidable Real Losses is included in the Economic Cost. Secondly, the Economic Cost should include a 'cost for carrying risk' and the key risks to be included in this regard are 'Demand Risk' and 'Recovery Risk'. There are various ways that these risks can be priced to include its impact in the Economic Cost. Experience indicates that many municipalities are pricing water services significantly below the Economic Cost. Determining and setting the appropriate tariff is a key step towards financial turn-around and sustainability.

It should also be noted that the Economic Cost is dynamic – as circumstances change so will this important parameter change. Capital expenditure, changes in the maintenance regime and changes in the overall risk profile are all examples of parameters that will impact on the Economic Cost.

Real Losses Revisited

Earlier in this article, it was noted that often there is an isolated focus on eliminating Real Losses in the system and a more integrated approach was urged. A different perspective in this context is to highlight the need to redesign municipal water distribution and reticulation systems with the specific aim to: (i) implement specific supply and recovery strategies, (ii) monitor and manage specific risks, (iii) monitor and verify overall system performance, (iv) detect leaks, wastage and Over Consumption and (v) collect data that will over time enhance knowledge and understanding of the system itself thereby facilitating better strategies and management. Any project through which large-scale repair, refurbishment or replacement of existing networks and systems is envisaged presents an ideal opportunity to implement a redesigned system. Such opportunities should not be missed.

What About the Future

Analysis of municipal water supply systems cannot focus only on current demand. Indeed, as mentioned previously the need to develop new, costly water resources to meet future/projected demand may be the very issue that triggers the rigorous analysis of the status quo. As is the case with the refurbishment of existing systems (as discussed in the previous paragraph) the expansion of a system or sub-system provides an ideal opportunity to implement a redesign of the system.

Municipal water supply systems have long planning horizons, which renders Demand Risk as one of the key risks to be managed. Future demand estimates should thus be based on a projection of the Zero Base System Demand. In this regard it would be critical to also project the impact of future development(s) on:

1. The Unavoidable Real Losses.
2. Envisaged changes in the profile of the consumer base which may impact on Recovery Risk.

Conclusion

In conclusion, the basis of a more integrated and holistic approach in the turnaround of municipal water supply systems and re-establishing financial viability and sustainability may be summarised as follows:

1. Use of a suitable model to establish the Zero Base System Demand and to quantify 'Demand Risk'.
2. Use of a suitable model to estimate the Unavoidable Real Losses.
3. Analysis of the consumer base to establish the different 'Recovery Risk' and consumption components and to suitably quantify the Risk Adjusted Revenue Volume.
4. Calculation of the existing Recovery Ratio of the municipality as a key performance measure signalling the need for intervention.
5. Calculation of the Economic Cost of water supply.
6. Adopting an appropriate tariff structure to facilitate and achieve specific strategies (such as eliminating Over Consumption etc.).
7. Identification and formulation of suitable Conservation projects on a zone -, district – or sub-regional basis through:
    a. Testing for the likely presence of Over Consumption and factors contributing towards Over Consumption.
    b. Estimation of the aggregate of Recoverable Real Losses and Over Consumption (i.e. ε).
    c. Redesign of the relevant supply system of elements thereof.
    d. Cost/benefit analysis through a suitable risk model.
8. Identification and formulation of suitable Demand Side projects on a zone -, district – or sub-regional basis through:
    a. Setting an appropriate target for the Recovery Ratio in the relevant zone, district or sub-region.
    b. Designing a suitable recovery strategy for the relevant zone, district or sub-region.
    c. Redesigning existing distribution and reticulation systems where necessary.
    d. Integrating future system requirements of the relevant zone, district or sub-region in the design.
    e. Conducting cost/benefit analysis through a suitable risk model.