Hydrogeology of the Dry Zone – Central Myanmar

A summary

Aqua Rock Konsultants
Citation
The full report can be downloaded at https://waterpartnership.org.au/publications/

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1 Introduction

This summary aims to provide an overview of the *Hydrogeology of the Dry Zone – Central Myanmar*, a major study by Dr Leonard Drury (2017), prepared with assistance from the Ministry of Agriculture, Livestock and Irrigation (MOALI). The study revises and updates hydrogeological surveys and a drilling program begun in the late 1970s to mid-1980s. It represents an understanding of the groundwater resources of the Dry Zone based on decades of experience from hydrogeologists from Myanmar and Dr Drury’s extensive international experience.

The summary is not suitable for practitioners to use for groundwater investigations. The full report includes detailed hydrogeological maps, cross sections and descriptions for the 11 designated areas within the Central Dry Zone. A free copy of the publication can be downloaded at https://waterpartnership.org.au/publications/

Groundwater has played an important role in the Dry Zone throughout recorded history. The hot mineral springs at Halin, near Shwebo, were used for bathing in the eighth century when the city was the capital of Upper Myanmar. Historians believe that during the Pagan Period, dugwells were used in the city of Bagan for domestic purposes and from that time dugwells were used throughout Central Myanmar.

Groundwater is critical to the livelihoods of the 15.4 million people (just under 30 percent of the population of Myanmar) who live in the Central Dry Zone. The Dry Zone is a climatic, geographical location, not an administrative boundary. It is defined as the area where rainfall is less than 1,000 millimetres (mm) per year and is within a rain shadow of the Rakhine Yoma.

Over the last 50 years, rural water supply has dominated groundwater development activities. Major campaigns to install wells for village water supply have been conducted by government and non-government agencies. The World Health Organisation (WHO), United Nations Children’s Fund (UNICEF) and the Australian Development Assistance Bureau (ADAB) constructed groundwater supplies in 3,100 villages in the Dry Zone between 1978 and 1986. Since 2008 the Japan International Co-operation Agency (JICA) and the Department of Rural Development (DRD) have undertaken village water supplies in many villages in the Dry Zone under the ‘22’, ‘87’ and ‘110’ tubewell programs. Many smaller NGOs and INGOs construct and rehabilitate village tubewells. A total of 13,355 domestic village tubewells have been constructed by IWUMD and predecessors throughout the Dry Zone. Tubewells and dugwells constructed by private individuals and NGOs may number in the hundreds of thousands.

Most villages, towns and cities in the Dry Zone use groundwater as their primary source for domestic and potable water, and it is used extensively for industrial purposes. Of the 44 main towns within Magway, Mandalay and Sagaing regions, 23 use groundwater as the main source, 14 use a mix of groundwater and surface water, and only seven towns (located mainly along watercourses) use surface water as their primary source. Towns with surface water as their primary supply still have large numbers of privately owned and operated tubewells and dugwells.

13,600 ha of formal irrigation schemes are sourced from groundwater, and recently there has been a rapid growth in farmer-managed pumping for small-scale irrigation.

Despite the importance of groundwater in the region, little information has been readily available on resources to support groundwater development and management.
Map 1: Geology of the Dry Zone

GEOLOGICAL MAP OF CENTRAL MYANMAR
INCLUDING MOST OF MANDALAY, MAGWAY AND SAGAING DIVISIONS

PLATE 1
2 Hydrogeology of the Dry Zone

Regional geological structures (Map 1) have major impacts on groundwater occurrence, direction of flow, depth to the potentiometric surface, presence of artesian flow and water quality. With an understanding of the geological setting, the associated hydrogeological characteristics can be interpreted, and groundwater yield and quality can be reasonably predicted.

The Dry Zone is ringed by steep, rugged highlands, with all mountain ranges being orientated roughly north to south. It is bounded in the west by the Naga and Chin hills and the Rakhine Yoma, in the central south by the Bago Yoma and in the east by the Sagaing Fault, which separates the basin from the older metamorphic Shan Plateau. Fertile alluvial soil is found along the Ayeyarwady River plains. Sagaing Region has the largest area of alluvial soil, Magway the least. Less fertile sandy land is located over sandstone outcrops, and poor soil of ‘badlands’ topography exists over marine shales.

The Inner Burman Tertiary Basin lies within the Dry Zone and runs from the Gulf of Martaban northwards to the Eastern Himalayas.

The Central Lowlands is a tectonically active area in the Dry Zone, with a complex system of faults, folds and thrusts resulting in multiple sub-basins within three main structural zones:

- **the Western Trough**, includes the Chindwin, and Minbu basins; the Pale and Salin sub-basins - a complex of Upper Cretaceous to Mid Tertiary marine and non-marine deposits overlain by younger (Upper Miocene to Recent) continental sediments (alluvial and colluvial deposits). Oil deposits are found mainly in the Middle Eocene to Middle Miocene rocks along the eastern edge of the Salin Sub-basin;

- **the Central Volcanic Line**, a volcanic arc, stretches intermittently between the Western and Eastern troughs for more than 400 kilometres, including NNW-SSE orientated volcanic complexes at Thayetmyo, Mount Popa, Shinmataung Range, Salingyi and Monywa; and

- **the Eastern Trough** includes the Sittaung, and Shwebo-Monywa basins, the Taungdwingyi Sub-basin and the Bago Yoma Anticlinorium. All basins are filled with Tertiary marine sediments with an increase in continental sediments to the north.

2.1 Principles of Groundwater Occurrence

Groundwater refers to water completely occupying all voids (saturated zone) within a geological stratum. The unsaturated zone (vadose zone) has voids which are filled with air and water. The vadose zone is found above the saturated zone and extends upwards to the ground surface. Rocks or unconsolidated sediment within the saturated zone that are sufficiently permeable to store and transmit quantities of water are called aquifers.

Table 1 indicates the main aquifers in the Dry Zone. The depth and their hydrogeological and hydrochemical characteristics are largely controlled by topographic location, mode of geological deposition and associated geological structure.
Table 1: Major Aquifer Units in the Dry Zone

<table>
<thead>
<tr>
<th>Formation</th>
<th>Area (%)</th>
<th>Lithology</th>
<th>Location</th>
<th>Mode of Deposition</th>
<th>Quality/Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alluvium</td>
<td>29</td>
<td>Sand, silty sand</td>
<td>Major watercourses, intermountain sub-basins</td>
<td>Fresh water fluvial</td>
<td>Usually low salinity, high yield</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sand, gravel, cobble</td>
<td>Eastern and western foothills</td>
<td>Fresh water colluvial</td>
<td>Low salinity, moderate yield</td>
</tr>
<tr>
<td>Piedmont</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrawaddy</td>
<td>38</td>
<td>Sand, sandstone, gravel,</td>
<td>Regional aquifer throughout Dry Zone</td>
<td>Fresh water fluvial, deltaic</td>
<td>Low salinity to brackish, moderate to</td>
</tr>
<tr>
<td>Formation</td>
<td></td>
<td>clay</td>
<td></td>
<td></td>
<td>high yield</td>
</tr>
<tr>
<td>Pegu Group</td>
<td>20</td>
<td>Sandstone, fractured shale</td>
<td>Central and west</td>
<td>Marine, fluvial and deltaic</td>
<td>Brackish to saline, low yield</td>
</tr>
<tr>
<td>Eocene</td>
<td>7</td>
<td>Sandstone, shale</td>
<td>Western foothills</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volcanics</td>
<td>1</td>
<td>Intrusive and extrusive</td>
<td>Central Volcanic Line / Secondary</td>
<td>Volcanic eruption or emplacement</td>
<td>High yield, low salinity, hard</td>
</tr>
</tbody>
</table>

2.2 Regional Hydrochemical Trends

Salinity – five salinity ranges have been developed based on the general usefulness of water. Variations in groundwater quality sometimes occur with depth and the presence and concentration of individual salts and gases. Specific conductance ranges and corresponding uses are:

- 0 to 1,500 µS.cm⁻¹: Good quality - usually suitable for drinking, stock, irrigation, town water supply and industry
- 1,500 to 3,000 µS.cm⁻¹: Fair quality - can be used for village water supply if necessary and all stock. Salt tolerant crops under favourable conditions
- 3,000 to 6,000 µS.cm⁻¹: Inferior quality - suitable mainly for stock and washing. Avoid consumption by villagers if possible
- 6,000 to 10,000 µS.cm⁻¹: Poor quality - suitable only for goats and sheep. Cattle will not tolerate > 8,000 µS.cm⁻¹
- Greater than 10,000 µS.cm⁻¹: Bad quality – unsuitable for any purpose except salt harvesting

Aquifer contamination – localised microbial pathogens may occur on some shallow aquifers (less than 10 metres) due to the pollution from vertical seepage of contaminated surface water, septic tanks, markets, abattoirs and industrial areas. Contamination in the Dry Zone may also occur in areas underlying petroleum and mining areas.

Tritium analysis - groundwater from 68 Dry Zone tubewells was tested by the Australian Atomic Energy Commission (AAEC) laboratory in 1986. Most resulted in a tritium activity under two tritium units (TU) indicating the water had been in the groundwater system for more than 30 years (that is, before atmospheric nuclear testing). Samples greater than 12 TU represent ‘Modern’ water which suggests proximity to recharge areas near to rivers. Readings between three to six TU are most likely a mixture of both Modern recharge and older groundwater.

Radiocarbon (C-14) Analysis - 10 samples were collected for C-14 dating to obtain preliminary estimates of groundwater age from different hydrogeological regimes. Analyses were undertaken in 2017 by the Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, Sydney. Groundwater ages from artesian and deep aquifer systems range from 1,355 ± 30 to 26,120 ± 120 years.

The C-14 analysis gives evidence of aquifer system dynamics: aquifer recharge and discharge areas can be located; duration of residence time, chemical reactions and flow direction within major regional systems can be understood; and practitioners and community can better conceptualise groundwater movement and appreciate the need for monitoring and implementation of management plans.

Arsenic in groundwater – the highest arsenic concentrations exceeding 50 µg/L are from the Ayeyarwady River sediments. Arsenic was below 10 µg/L in aquifers in the Mu and Chindwin river townships.
2.3 Hydrogeological Interpretation for the 11 Designated Areas of the Dry Zone

The hydrogeological interpretation for the 11 chapters of the main report (see Chapters 6-16 from https://waterpartnership.org.au/publications/#hydrogeology) is mainly based on village water supply data supplied by the IWUMD and through personal experience. Due to the construction of small diameter village tubewells, the IWUMD information lacks hydraulic characteristics from pump-out tests. Some other sources have supplemented information gaps. The number of tubewells considered is small compared to the hundreds of thousands of private tubewells and dugwells. However, quality of information, not quantity is critical to hydrogeological interpretation.

The regional hydrogeological and hydrochemical maps are intended as a broad guide to the groundwater resources of Central Myanmar. More field studies may be required when future groundwater development is planned. The 11 areas are shown on Map 2. The area/chapter layout is:

- **Area 1**: Chauk-Yenangyaung-Kyaukpadaung (Chapter 6)
- **Area 2**: Magway-Minbu (Chapter 7)
- **Area 3**: Taungdwingyi Sub-basin (Chapter 8)
- **Area 4**: Pakokku (Chapter 9)
- **Area 5**: Pale Sub-basin (Chapter 10)
- **Area 6**: Lower Chindwin River Valley (Chapter 11)
- **Area 7**: Mu River Valley (Chapter 12)
- **Area 8**: Nyaung Oo-Kyaukpadaung (Chapter 13)
- **Area 9**: Myingyan-Ngazun-Mahlaing (Chapter 14)
- **Area 10**: Wundwin-Thazi-Tatkon (Chapter 15)
- **Area 11**: Myittha-Mandalay (Chapter 16)

A sample of detailed hydrogeological information is given for Area 4 Pakokku District (Chapter 9).

The Pakokku area is geologically complex. It is situated in the upper part of the Minbu Basin towards the 22° N Uplift. Regional structures include the Kabet-Shinmataung Anticline, Shinmataung Fault, Pakokku Syncline, Myaing and Letpanto anticlinal complexes, Medin Fault, Myaing-Kyaukpadaung and Bahin-Pagan structural lines, Yenangyat Anticline and Yenangyat Thrust Fault. The axis of the Salin Syncline is to the west of the features shown on Maps 3 and 4.

The Eocene to Mid Eocene rocks of Myaing, Letpanto and Yenangyat are highly fractured. They appear as tight, ripple-like, elongated, symmetrical folds segmented by transverse faults. Major gas and oil fields occur in the Yenangyat and Letpanto areas.

The easterly dipping rocks of the Shinmataung Range also are highly faulted. Typical aquifer details in various rocks and geographical locations are given in Table 2.
Map 2: 11 Designated Areas of Study in The Dry Zone, Central Myanmar

1. Chauk - Yenangyaung - Kyauk padaung
2. Magwe - Minbu
3. Taungdwingyi Sub-Basin
4. Pakokku
5. Pale Sub-Basin
6. Lower Chindwin River Valley
7. Mu River Valley
8. Nyaung Oo to Kyauk padaung
9. Myingyan – Ngazun – Mahlaing
10. Wundwin – Thazi – Tatkon
11. Myittha to Mandalay
Map 3 Schematic Geological and Hydrogeological Map: Pakokku
Map 4: Hydrogeological Cross Section and Specific Conductance: Pakokku
Map 4 (continued): Hydrogeological Cross Section and Specific Conductance: Pakokku
### Table 2: Aquifer Details from Various Rock Types in the Pakokku Area

<table>
<thead>
<tr>
<th>Formation</th>
<th>Area</th>
<th>Village</th>
<th>Tubewell number</th>
<th>Surface Elevation (m AMSL)</th>
<th>All data from surface (m)</th>
<th>DD (m)</th>
<th>Airlift Yield (L/sec)</th>
<th>Transmissivity (m²/d)</th>
<th>Specific Conductivity (µS.cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Depth</td>
<td>Aquifer</td>
<td>SWL</td>
<td>DDL</td>
<td></td>
</tr>
<tr>
<td>Eocene</td>
<td>Letpanto</td>
<td>Pauk Khaung</td>
<td></td>
<td></td>
<td>180</td>
<td>100 - 115</td>
<td>155 - 165</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>Pegu/Irrawaddy</td>
<td>Shinmataung</td>
<td>Kyiyya</td>
<td>1062</td>
<td>+ 86</td>
<td>146</td>
<td>83 - 91</td>
<td>27 - 37</td>
<td>36</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Antcline</td>
<td>Htan Nge Taw</td>
<td>+ 90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Myitche</td>
<td>Horse breeding</td>
<td>3370</td>
<td>+ 61</td>
<td>58</td>
<td>17 - 55</td>
<td>12</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Myit Chay</td>
<td>+ 60</td>
<td></td>
<td>43</td>
<td>38 - 41</td>
<td>9</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aing Gyi</td>
<td>+ 58</td>
<td></td>
<td>40</td>
<td>35 - 38</td>
<td>5</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Chaungmagyi</td>
<td>Zigon West</td>
<td>4176</td>
<td>+ 102</td>
<td>104</td>
<td>82 - 101</td>
<td>44</td>
<td>48</td>
<td>4</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Pale Sub-basin</td>
<td>Damathaya (see Ch. 10)</td>
<td>3478</td>
<td>+ 138</td>
<td>202</td>
<td>174 - 195</td>
<td>24</td>
<td>31</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Pakokku Syncline</td>
<td>Kangyigon</td>
<td>3362</td>
<td>+ 128</td>
<td>95</td>
<td>62 - 92</td>
<td>13</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kontakton</td>
<td>4167</td>
<td>+ 122</td>
<td>128</td>
<td>101 - 125</td>
<td>56</td>
<td>59</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GTC station</td>
<td>+ 135</td>
<td></td>
<td>91</td>
<td>55 - 61</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial Zone</td>
<td>+ 120</td>
<td></td>
<td>79</td>
<td>64 - 70</td>
<td>23</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Irrawaddy</td>
<td>Shainggaung</td>
<td>5415</td>
<td>+ 205</td>
<td>198</td>
<td>177 - 186</td>
<td>122</td>
<td>129</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ta Naung</td>
<td>+ 210</td>
<td></td>
<td>50</td>
<td>38 - 41</td>
<td>19</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Sinsein</td>
<td>5409</td>
<td>+ 305</td>
<td>70</td>
<td>57 - 66</td>
<td>20</td>
<td>23</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Shinmataung</td>
<td>Thadaing</td>
<td>0746</td>
<td>+ 76</td>
<td>36</td>
<td>32 - 35</td>
<td>8</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Htan Nge Taw</td>
<td>+ 90</td>
<td></td>
<td>146</td>
<td>28 - 36</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>South Pakokku</td>
<td>Leya</td>
<td>3575</td>
<td>+ 73</td>
<td>62</td>
<td>41 - 57</td>
<td>9</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mongon</td>
<td>3603</td>
<td>+ 61</td>
<td>47</td>
<td>29 - 37</td>
<td>9</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>North Pakokku</td>
<td>Magyibinpu</td>
<td>4165</td>
<td>+ 61</td>
<td>52</td>
<td>39 - 46</td>
<td>4</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inma</td>
<td>1605</td>
<td>+ 55</td>
<td>31</td>
<td>21 - 27</td>
<td>8</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Yaw Chaung</td>
<td>Sanyaun</td>
<td>4327</td>
<td>+ 173</td>
<td>40</td>
<td>24 - 34</td>
<td>6</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

¹ Intermittent chaung recharge into Pondaung Sandstone

Source: IWUMD database.
3 Regional Hydrogeology and Groundwater Resources Management

3.1 Hydrogeological Understanding of the Dry Zone

The Dry Zone is effectively encapsulated within a sedimentary basin. Within this complex geological setting, the associated hydrogeological characteristics can be reasonably understood and interpreted.

The Alluvium commences 65 kilometres upstream of Mandalay, is joined by extensive sedimentary deposits from the Mu and Chindwin river systems and terminates on the 20° N Uplift Syntaxis. It is enclosed to the east by the Shan Plateau and west by the Chin Hills-Rakhine Yoma. Centrally it is split by the Bago Yoma Anticlinorium. To the southeast, the hydrogeological boundary near Yamethin separates groundwater flow between the Samon Chaung (Ayeyarwady River) and Sinthe Chaung (Sittaung River).

The Irrawaddy Formation has similar peripheral hydrogeological restrictions.

Plates 3a, 3b, and 3c of the main text indicate a wide variety of information relating to such characteristics as elevated groundwater temperature, artesian flows, age of water, contaminants, drilling problems, salinity levels in relation to rock types, aquifer yields, areas of natural recharge and discharge.

3.2 Groundwater Availability and Dynamics

To manage groundwater sustainably, it is essential to understand both the size and dynamics of the resource – that is, where and at what rate water is entering (recharge) and leaving (discharge) the system. As a general guideline, groundwater extraction should not exceed aquifer recharge.

Groundwater recharge is primarily from rainfall, by direct precipitation and infiltration of surface runoff. Groundwater levels in wells adjacent to the Ayeyarwady River fluctuate with the river height, indicating that aquifers close to the river have a direct hydraulic connection to the river. During flood periods, a localised reversal in groundwater movement may occur, with recharge from the river to the aquifers. In general, groundwater flow is towards the rivers, particularly in the dry season, when groundwater supplies a significant proportion of base flow. Temporary reversal in groundwater flow direction during flood events is likely to be of short duration.

In general, groundwater in the Dry Zone moves from elevated areas down gradient to discharge directly or indirectly (through tributaries) to the major rivers. Groundwater contributes a significant proportion of baseflow in rivers and streams. Preliminary estimates indicate that around 20 percent of dry season flow in the Ayeyarwady River below Magway is from groundwater. Discharge also occurs from natural springs.

Extraction of water for use is also a significant component of discharge, through the large number of artesian and sub-artesian tubewells and dugwells; and from pumped wells.

3.3 Water Balance Models

To assess groundwater availability in the Dry Zone, water balance models were developed to evaluate the dynamics of the groundwater system within individual sub-basins. Below is an example for the Ayeyarwady River Corridor (ARC) - between Mandalay and Magway, including the Samon Chaung Valley, Salin and Taungdwingyi sub-basins and outflow from the Lower Mu River. These results suggest that there are significant areas in the Dry Zone where more groundwater could be extracted, but caution is required in respect to the impact on shallow tubewells, water quality and environmental requirements.
Although the aquifers of the Dry Zone constitute a very large resource of stored groundwater, only a small percentage of this volume is available for extraction. The slow recharge rates, reflected in much of the groundwater sampled being greater than 1000 years in age, means that systems must be managed in balance with local recharge to prevent depletion and drawdown.

### 3.4 Sustainable Groundwater Management

To achieve sustainable groundwater development and management within the Dry Zone it is critical to adequately understand the hydrogeological regime.

Groundwater extraction in Myanmar has occurred over many centuries, yet the nature and occurrence of this subterranean resource is not fully understood. This is due to a lack of detailed and documented groundwater studies, no shared reliable database, a lack of long-term monitoring and an absence of computer modelling.

After 50 years of rural water supply projects there are still many areas where unsafe drinking water is still accessed from village ponds. This mysterious ideology is reflected in the lack of a groundwater law and regulations and no formal groundwater management authority.

With severe temperatures, lack of Dry Season rainfall and predicted climate change, substantial pressure is being applied to the nation’s water resources. Groundwater needs to be recognised as a crucial asset and an integral part of Myanmar’s long-term water planning.

To effectively manage this subsurface water system, it needs to be better understood by adequate investigation and documentation. Groundwater management is a challenge, requiring an integration of scientific knowledge, strong government support and community consultation. Groundwater and surface water need to be viewed as one integrated resource and mutually interdependent.

For sustainable development of the groundwater resources in the Dry Zone a series of actions need to be implemented. It is essential to have access to a reliable centralised database and
hydrogeological computer models. The impact of aquifer recharge and discharge on the potentiometric surface needs to be evaluated by long-term monitoring.

In the Dry Zone monitoring needs to be carried out:

- in each of the groundwater irrigation areas (Pale Sub Basin, Monywa, Ayadaw, Meiktila, Pyaybwe, Takton);
- farmer-owned shallow irrigation areas (Kyauske, Salin Basin);
- areas of saline/brackish water (Myingyan); and
- city and town water supplies (Mandalay City, Magway, Thazi, Pakokku, Minbu).
- Hydrochemical monitoring should be included at the Monywa Copper Mine; the oilfields; and urban market and industrial areas.

Within Myanmar there is a deficiency in groundwater modelling expertise. Computer based mathematical groundwater models are a valuable predictive management tool. They enable the simulation of local and regional aquifer systems under various operational scenarios. These models are used to represent the natural groundwater flow in various hydrogeological environments. They can predict aquifer recharge and discharge; local effects of groundwater extraction; fate of pollutants; hydrochemical changes in rural, urban or hypothetical scenarios; and impacts of climate change. Without such expertise, the effective management of the groundwater resource is highly restricted.

Throughout the Dry Zone there are many flowing tubewells, both within and outside designated artesian irrigation areas. High pressure aquifers are associated with geological structure and mountain recharge producing high potentiometric surface in the lowlands.

Artesian flows are uncontrolled and large volumes of this precious resource is wasted. When not used for irrigation or domestic purpose most flows from tubewells are not capped.

An example of successful works of such an aquifer system is the Great Artesian Basin, Australia.

The impact of climate change on groundwater management needs to be considered. Due to its large capacity groundwater may be more capable to buffer the impact of climate variability than surface water. However, groundwater is not exempt from the effects of drought and discharge via evapotranspiration.
4 Future Development

Groundwater should not be viewed as a single, sole-source entity but as one component within a basin-wide water management system.

Recommended groundwater management tools include:

- the development of a central database, available to all groundwater practitioners;
- approval for Groundwater Legislation and Regulations to manage groundwater extraction, monitoring, management, funding, pollution, remediation, tubewell construction, drillers licensing and regulation enforcement;
- establishment of a groundwater monitoring system in major aquifer systems;
- train personnel in groundwater modelling capability to enable the simulation of local and regional aquifer systems under various operational scenarios; and
- application of flow control and rehabilitation practices to some artesian aquifers.

Regular revision of hydrogeological and hydrochemical data is required to maintain an up-to-date picture of the groundwater needs of Central Myanmar. The information gathered would then be available to review the text of the ‘Hydrogeology of the Dry Zone – Central Myanmar’ and better serve groundwater infrastructure development in the future.