Characteristics of Irrigation Pump Performance in Major Irrigated Areas of California

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Irrigation Training and Research Center

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CHARACTERISTICS OF IRRIGATION PUMP PERFORMANCE IN
MAJOR IRRIGATED AREAS OF CALIFORNIA

Pumping data was collected from over 15,000 well and non-well pumps throughout the Sacramento, Salinas, and San Joaquin Valley groundwater basins of California. Each of these basins is divided into a number of subbasins. A map of the general layout is shown below (gray lines outside of basins represent county lines; gray lines inside basins represent subbasins).

Figure 1: Groundwater basins in California.

Data was analyzed by basin and subbasin for well pumps and non-well pumps. For each pump type, averages were calculated based on:

- The whole basin
- Overall pumping plant efficiency (OPPE)
- kWh/AF
- Subbasins

General conclusions were drawn for each set of averages, and a final summary of conclusions is given at the end of each pump type section.
Well Pump Subbasin Comparisons
Over the three groundwater basins, 12,876 well pump tests were performed. The following table summarizes the averages of a variety of factors from well pump tests in each of the three groundwater basins.

Table 1: Summary of regional well pump test data.

<table>
<thead>
<tr>
<th></th>
<th>Salinas</th>
<th>Sacramento</th>
<th>San Joaquin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Input Power [kW]</td>
<td>65</td>
<td>451</td>
<td>478</td>
</tr>
<tr>
<td>Average Weighted kWh/AF</td>
<td>56</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>Average Weighted TDH [ft]</td>
<td>289</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td>Average Weighted Flow Rate [GPM]</td>
<td>244</td>
<td>1,197</td>
<td>1,197</td>
</tr>
<tr>
<td>Average Weighted SWL [ft]</td>
<td>260</td>
<td>1099</td>
<td>1099</td>
</tr>
<tr>
<td>Average Weighted Drawdown [ft]</td>
<td>1,553</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Average Weighted Motor HP</td>
<td>189</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Average Weighted OPPE [%]</td>
<td>43</td>
<td>93</td>
<td>93</td>
</tr>
</tbody>
</table>

1 All weighted values are weighted by input power (kW)
2 Total Dynamic Head
3 Distance from Surface to Standing Water Level
4 Overall Pumping Plant Efficiency

When comparing the data from the three basins, some general observations regarding the well pump data can be made:

1. All three basins have very similar average OPPE (~56%).
2. The Salinas basin’s well pump tests had a slightly higher average input power than the well pump tests in the other basins.
3. The Sacramento basin’s well pump tests had a higher average flow rate and lower average kWh/AF, total dynamic head, motor HP, and depth to standing water level than the well pump tests in the other basins.
4. The San Joaquin basin’s well pump tests had a greater average depth to standing water level and average drawdown than the well pump tests in the other basins.
Regional Comparison by Overall Pumping Plant Efficiency (OPPE)
The data for each basin was compared with overall pumping plant efficiency (%) to:

- Test Distribution
- Average Input Power [kW]
- Average kWh/AF (weighted by input power)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power)
- Average Flow Rate [ft] (weighted by input power)
- Average Depth to Standing Water Level (SWL) [ft] (weighted by input power)
- Average Drawdown [ft] (weighted by input power)
- Average Motor HP (weighted by input power)

The values are grouped into 10% ranges, with the point at the midpoint of the range (for example, the average value for the 21-30% range is placed at the 25% point). The grayed areas show the ranges where a majority of the values lie.
When comparing the data from the three basins to the overall pumping plant efficiency, some general observations regarding the well pump data can be made:

1. A majority of the well pump tests fall between the 40-70% overall pumping plant efficiency ranges.
2. Across nearly all of the overall pumping plant efficiency ranges, the Sacramento basin’s well pump tests have a higher flow rate, and a lower kWh/AF and total dynamic head than the well pump tests in the other basins.
3. The San Joaquin basin’s well pump tests had higher average drawdown values than the well pump tests in the other basins.
4. The average depth to the standing water has a lot of variation between basins.
Regional Comparison by Energy Consumption per Volume Pumped

The data for each basin was compared with kWh/AF to:

- Test Distribution
- Average Input Power [kW]
- Average Total Dynamic Head (TDH) [ft] (weighted by input power)
- Average Flow Rate [ft] (weighted by input power)
- Average Depth to Standing Water Level (SWL) [ft] (weighted by input power)
- Average Drawdown [ft] (weighted by input power)
- Average Motor HP (weighted by input power)
- Average Overall Pumping Plant Efficiency (OPPE) [ft] (weighted by input power)

The values are grouped into ranges of 100 kWh/AF with the point at the midpoint of the range (for example, the average value for the 201-300 kWh/AF range is placed at the 250 kWh/AF point). Each basin had a single data point placed at 1000 kWh/AF that represents the y-axis average value for all data points greater than 1,000 kWh/AF. The grayed areas show the ranges where a majority of the values lie.
When comparing the data from the three basins to the kWh/AF, some general observations regarding the well pump data can be made:

1. A majority of the well pump tests fall between 200 and 500 kWh/AF.
2. The Sacramento basin well pump tests differ from the well pump tests in other basins at higher (600+) kWh/AF in all categories. No conclusions are drawn from this data due to the small sample sizes in those ranges.
3. The well pumps tested in the Sacramento and Salinas basins have higher average input power in the 200-500 kWh/AF range than the well pumps in the San Joaquin basin. However, the average input power increases with kWh/ah, and the Salinas and San Joaquin basins have more tests in the higher ranges (400+) than the Sacramento basin. This could explain why the Sacramento and San Joaquin basin-wide averages are nearly equal, and the Salinas basin average is slightly higher.
4. Average regional flow rates vary significantly at low (0-300) kWh/AF, but match well at higher (400+) kWh/AF. Only the Sacramento basin has a significant number of well pump
tests in that range (see Graph 9). These low kWh/AF, high flow rate pumps are probably causing the Sacramento basin tests’ average flow rate to be so much higher than the test averages in the other basins.

5. The San Joaquin basin’s well pump tests do not appear to have a significantly greater drawdown than the other basins (see Graph 14). This can be explained mainly by the distribution of tests. The San Joaquin basin has a significant percent of its tests in the 500-800 kWh/AF range (see Graph 9), and the tests in those ranges have higher drawdown values than the 0-500 kWh/AF ranges and the Salinas basin (which also has a significant percent of its tests in the higher range) and input power (what the average drawdown values are weighted by) than in the 0-500 kWh/AF ranges. This could cause the basin’s overall higher value, without making the values in the 200-500 range significantly higher in comparison to the other two basins.

6. The average total dynamic head in each kWh/AF range is almost identical for the three basin averages, even though the average total dynamic head of the Sacramento basin well pump tests was lower than the tests other basins. This is probably due to the fact that the majority of the well pump tests in the Sacramento basin had slightly lower kWh/AF than the well pump tests in the other basins; the lower kWh/AF ranges had lower average total dynamic heads for all basins.

7. The average depth to standing water level increases with the kWh/AF, possibly indicating the effect larger pumps are having on their local water tables.
Regional Comparison by Subbasin
Maps were created characterizing the groundwater subbasins according to available pump data. The Central Valley of California can be divided into three basins (Salinas, Sacramento, and San Joaquin Valley), each divided into a number of subbasins to examine the validity of the regional conclusions.

The following maps illustrate the three groundwater basins (and their subbasins) with varying parameters:

- Average Input Power [kW] (Map 1)
- Average kWh/AF (weighted by input power) (Map 2)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Map 3)
- Average Flow Rate [ft] (weighted by input power) (Map 4)
- Average Depth to Standing Water Level (SWL) [ft] (weighted by input power) (Map 5)
- Average Drawdown [ft] (weighted by input power) (Map 6)
- Average Motor HP (weighted by input power) (Map 7)
- Average Overall Pumping Plant Efficiency (OPPE) [%] (weighted by input power) (Map 8)
Map 3: Average total dynamic head (TDH) [ft] (weighted by input power).

Map 4: Average flow rate [ft] (weighted by input power).

Map 5: Average depth to standing water level (SWL) [ft] (weighted by input power).

Map 6: Average drawdown [ft] (weighted by input power).
When comparing the data from the three basins by subbasin, some general observations regarding the well pump data can be made:

1. There are clear basin trends for average input power, kWh/AF, total dynamic head, flow rate, depth to standing water, and motor HP (it does not appear that certain sub-basins are heavily skewing the data).

2. The Sacramento basin has one subbasin (5-21.64) that has well pump test values that differ greatly from the rest of the basin. This subbasin has only 7 tests, 3 of which are very large pumps (input power greater than 100 kW, motor HP greater than 100, discharge pressure greater than 100 psi, flow rate greater than 1000 GPM, total dynamic head greater than 375 ft, and kWh/AF greater than 500) with high overall pumping plant efficiencies (greater than 68%).

3. The San Joaquin basin appears to have more extreme well pump test values in the southern portion compared to the northern portion.

4. When comparing the overall pumping plant efficiency (OPPE) (a calculation based on the input power, flow rate, and total dynamic head), the Salinas and Sacramento basins’ well pump tests have a slightly lower average OPPE than the San Joaquin basin; however, the majority of subbasin average OPPEs can be contained between 54% and 62%.
Summary of Major Well Pump Testing Regional Conclusions

The major conclusions drawn from the well pump test data include:

1. All three basins’ well pump tests have very similar average weighted overall pumping plant efficiencies (~56%), with the majority of the values contained between 54% and 62%.

2. A majority of the well pump tests fall between 200 and 500 kWh/AF.

3. The basins have trends in data between the Sacramento, Salinas, and San Joaquin basins.
   a. In general, the Salinas basin well pump tests had, in relation to the well pump tests in the other basins:
      i. Slightly higher input power
   b. In general, the Sacramento basin well pump tests had, in relation to the well pump tests in the other basins:
      i. Lower kWh/AF
      ii. Lower total dynamic head
      iii. Higher flow rates
      iv. Lower depths to the standing water level
      v. Slightly lower motor HP
   c. In general, the San Joaquin basin well pump tests had, in relation to the well pump tests in the other basins:
      i. Greater depths to the standing water level
      ii. Higher drawdown

4. The San Joaquin basin’s well pump tests had more extreme values in most categories in the southern region as compared to the northern region.

5. The Sacramento basin has one subbasin (5-21.64) that has well pump test values that differ greatly from the rest of the basin. This subbasin has only 7 tests, 3 of which are very large pumps (input power greater than 100 kW, motor HP greater than 100, discharge pressure greater than 100 psi, flow rate greater than 1000 GPM, total dynamic head greater than 375 ft, and kWh/AF greater than 500).

6. The average depth to standing water level varies greatly between basins.

7. Within each basin, the average depth to standing water level increases with the kWh/AF, possibly indicating the effect larger pumps are having on their local water tables.

8. About 7% of the Sacramento basin’s well pump tests are low (0-100) kWh/AF, high (>2000) flow well pumps.
Non-Well Pump Subbasin Comparisons
Over the three groundwater basins, 2,874 non-well pump tests were performed. The following table summarizes the averages of a variety of factors from non-well pump tests in each of the three groundwater basins.

<table>
<thead>
<tr>
<th></th>
<th>Average Input Power</th>
<th>Average Weighted kWh/AF</th>
<th>Average Weighted TDH</th>
<th>Average Weighted Discharge Pressure</th>
<th>Average Weighted Flow Rate</th>
<th>Average Weighted Motor HP</th>
<th>Average Weighted OPPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinas</td>
<td>55</td>
<td>411</td>
<td>211</td>
<td>76</td>
<td>13,621</td>
<td>98</td>
<td>55</td>
</tr>
<tr>
<td>Sacramento</td>
<td>59</td>
<td>220</td>
<td>82</td>
<td>29</td>
<td>1,259</td>
<td>106</td>
<td>54</td>
</tr>
<tr>
<td>San Joaquin</td>
<td>40</td>
<td>152</td>
<td>24</td>
<td>36</td>
<td>3,960</td>
<td>131</td>
<td>58</td>
</tr>
</tbody>
</table>

1 All weighted values are weighted by input power (kW)
2 Total Dynamic Head
3 Overall Pumping Plant Efficiency

When comparing the data from the three basins, some general observations regarding the non-well pump data can be made:

1. All 3 basins’ non-well pump tests have similar average overall pumping plant efficiencies (~55%).
2. For almost all other values, the Sacramento and Salinas basins are the two extremes, with San Joaquin in between.
3. The Sacramento basin’s non-well pump tests have a much higher average flow rate, slightly higher average motor HP, and lower average kWh/AF, total dynamic head, and discharge pressure than the other basins.
4. The Salinas basin’s non-well pump tests have a higher average kWh/AF, total dynamic head, and discharge pressure, and a lower average flow rate than the other basins.
5. The San Joaquin basin’s non-well pump tests have lower input power than the other basins.
Regional Comparison by Overall Pumping Plant Efficiency (OPPE)
The data for each basin was compared with overall pumping plant efficiency (%) to:

- Test Distribution
- Average Input Power [kW]
- Average kWh/AF (weighted by input power)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power)
- Average Discharge Pressure [psi] (weighted by input power)
- Average Flow Rate [ft] (weighted by input power)
- Average Motor HP (weighted by input power)

The values are grouped into 10% ranges, with the point at the midpoint of the range (for example, the average value for the 21-30% range is placed at the 25% point). The grayed areas show the ranges where a majority of the values lie.
When comparing the data from the three basins to the overall pumping plant efficiency (OPPE), some general observations regarding the non-well pump data can be made:

1. A majority of the non-well pump tests fall between the 40-80% OPPE ranges; however, the distributions are very different by basin, and the peak values occur in different ranges (60-70% for Salinas, 50-60% for Sacramento, and 80-90% for San Joaquin).
2. Across nearly all of the OPPE ranges, the Sacramento basin’s non-well pump tests have a much higher average flow rate, and a lower average kWh/AF, total dynamic head, and discharge pressure than the non-well pump tests in other basins.
3. Across nearly all of the OPPE ranges, the Salinas basin’s non-well pump tests have a higher average kWh/AF, total dynamic head, discharge pressure, and motor HP and a lower average flow rate than the non-well pump tests in other basins.
4. Across nearly all of the OPPE ranges, the San Joaquin basin’s non-well pump tests have a lower average input power than the non-well pump tests in other basins.
Regional Comparison by Energy Consumption Per Volume Pumped
The data for each basin was compared with kWh/AF to:

- Test Distribution (Graph 24)
- Average Input Power [kW] (Graph 25)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Graph 26)
- Average DischargePressure [psi] (weighted by input power) (Graph 27)
- Average Flow Rate [ft] (weighted by input power) (Graph 28)
- Average Motor HP (weighted by input power) (Graph 29)
- Average Overall Pumping Plant Efficiency (OPPE) [%] (weighted by input power) (Graph 30)

The values are grouped into ranges of 100 kWh/AF with the point at the midpoint of the range (for example, the average value for the 201-300 kWh/AF range is placed at the 250 kWh/AF point). Each basin had a single data point placed at 1000 kWh/AF that represents the y-axis average value for all data points greater than 1,000 kWh/AF. The grayed areas show the ranges where a majority of the valueslie.
When comparing the data from the three basins to the kWh/AF, some general observations regarding the non-well pump data can be made:

1. The peak percent of total tests for each basin occurs in a different range. For the Sacramento basin, the peak is in the 0-100 kWh/AF range; for Salinas, the peak is in the 200-300 kWh/AF range; for San Joaquin, the peak is in the 100-200 kWh/AF range.
2. The Sacramento basin’s non-well pump tests differs from the rest at higher (600+) kWh/AF in all categories. No conclusions are drawn from this data due to the small sample sizes in those ranges.
3. There is a large variation in basin non-well pump test values for the input power and average weighted flow rate in the 0-200 kWh/AF range (where a significant portion of the Sacramento and San Joaquin basin tests occurred).
Regional Comparison by Subbasin
Maps were created characterizing the groundwater subbasins according to available pump data. The Central Valley of California can be divided into three basins (Salinas, Sacramento, and San Joaquin Valley), each divided into a number of subbasins to examine the validity of the regional conclusions.

The following maps illustrate the three groundwater basins (and their subbasins) with varying parameters:

- Average Input Power [kW] (Map 9)
- Average kWh/AF (weighted by input power) (Map 10)
- Average Total Dynamic Head (TDH) [ft] (weighted by input power) (Map 11)
- Average Discharge Pressure [psi] (weighted by input power) (Map 12)
- Average Flow Rate [ft] (weighted by input power) (Map 13)
- Average Motor HP (weighted by input power) (Map 14)
- Average Overall Pumping Plant Efficiency (OPPE) [%] (weighted by input power) (Map 15)
Map 11: Average total dynamic head (TDH) [ft] (weighted by input power).

Map 12: Average discharge pressure [psi] (weighted by input power).

Map 13: Average flow rate [ft] (weighted by input power).

Map 14: Average motor HP (weighted by input power).
When comparing the data from the three basins by subbasin, some general observations regarding the non-well pump flow rate data can be made:

1. The Sacramento and San Joaquin basins’ non-well pump tests do not have basin-wide trends like the basins’ well pump tests appeared to have. The basins seem to have a range of values, without any clear regional trends. Subbasins with extreme values appear to weight the basin’s average values.

2. The Sacramento basin has one subbasin (5-21.61) that has non-well pump test values that differ greatly from the rest of the basin. This subbasin has 17 tests, 8 of which are very large, high flow/lower head pumps (input power greater than 150 kW, motor HP greater than 250, discharge pressure less than 10 psi, flow rate greater than 40,000 GPM, total dynamic head less than 10 ft, and kWh/AF less than 30) with low overall pumping plant efficiencies (28-52%).

3. The Salinas basin appears to have the following basin-wide trends: high average total dynamic head, discharge pressure, and kWh/AF, and low average flow rate. This trend could be attributed to the relatively small size of the basin.
Summary of Major Non-Well Pump Testing Regional Conclusions

The major conclusions drawn from the non-well pump test data include:

1. All three basins’ non-well pump tests have very similar average weighted overall pumping plant efficiencies (OPPE) (~55%), and a majority of the subbasin average OPPEs can be contained between 53% and 67%. However, the distributions are very different by basin, and the peak OPPE values occur in different ranges (60-70% for Salinas, 50-60% for Sacramento, and 80-90% for San Joaquin).

2. The kWh/AF range with the peak percent of total non-well pump tests for each basin occurs in a different range. For the Sacramento basin, the peak is in the 0-100 kWh/AF range; for Salinas, the peak is in the 200-300 kWh/AF range; for San Joaquin, the peak is in the 100-200 kWh/AF range.

3. The Sacramento and San Joaquin basins’ non-well pump tests do not appear to have basin-wide trends like the basins’ well pump tests appear to have. The basins seem to have a range of values, without any clear regional trends. Subbasins with extreme values appear to weight some of the basins’ average values.

4. The Sacramento basin has one subbasin (5-21.61) that has non-well pump test values that differ greatly from the rest of the basin. This subbasin has 17 tests, 8 of which are very large, high flow-low head pumps (input power greater than 150 kW, motor HP greater than 250, discharge pressure less than 10 psi, flow rate greater than 40,000 GPM, total dynamic head less than 10 ft, and kWh/AF less than 30) with low overall pumping plant efficiencies (28-52%). These tests contribute to the differences found in the overall basin averages.

5. The Salinas basin’s non-well pump tests appear to have the following basin-wide trends:
   a. Higher average total dynamic head
   b. Higher discharge pressure
   c. Higher kWh/AF
   d. Lower average flow rate

This is relative to the non-well pump tests in the other basins. This trend could possibly be attributed to the relatively small size of the basin (less sub-basins to be in same range).
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