EMERGY SYNTHESIS 5:
Theory and Applications of the Emergy Methodology

Proceedings from the Fifth Biennial Emergy Conference,
Gainesville, Florida

Edited by
Mark T. Brown
University of Florida
Gainesville, Florida

Managing Editor
Sharlynn Sweeney
University of Florida
Gainesville, Florida

Associate Editors
Daniel E. Campbell
US EPA
Narragansett, Rhode Island

Shu-Li Huang
National Taipei University
Taipei, Taiwan

Enrique Ortega
State University of Campinas
Campinas, Brazil

Torbjorn Rydberg
Centre for Sustainable Agriculture
Uppsala, Sweden

David Tilley
University of Maryland
College Park, Maryland

Sergio Ulgiati
Parthenope University of Napoli
Napoli, Italy

December 2009

The Center for Environmental Policy
Department of Environmental Engineering Sciences
University of Florida
Gainesville, FL
The Emergy Basis for Formal Education in the United States

Daniel E. Campbell and HongFang Lu

ABSTRACT

The education system of the United States from 1870 to 2006 was evaluated using emergy methods. The system was partitioned into three subsystems, elementary, secondary, and college education and the emergy inputs required to support each subsystem were determined for each year over the period of analysis. The emergy required to produce an individual with a given level of education was calculated by summing over the years of school needed to attain that level of knowledge. In 1980, the emergy per individual varied from 11.5 E16 sej/ind for a pre-school student to 157.4 E16 sej/ind for a PhD. The emergy of teaching and learning per hour spent in these processes was calculated as the sum of the emergy delivered by the education and experience of the teachers and the emergy brought to the process of learning by the students. The emergy of teaching and learning was an order of magnitude larger than the annual emergy required for the U.S. education system. The implication is that teaching and learning is a higher order social process related to the maintenance of the information cycle of the Nation. The results show that there is a ten-fold return on the emergy invested in operating the education system of the U.S.

INTRODUCTION

During the past 160 years human beings have come to control many of the living and nonliving system operations on the surface of the Earth. The world has become a human-dominated system (Vernadsky 1945, Vitousek et al. 1997a, Campbell et al. 2009), in which human agency accounts for and controls the majority of the material and energy flows (Vitousek et al. 1997b) of the biosphere. Odum (1996) characterized human beings as Earth’s information processors. He pointed out that humans arose late in the evolutionary process of the Earth and that they have highly developed information processing organs and use social mechanisms for group information processing, e.g., art, music, sports, etc. Because of the importance of human knowledge in mankind’s control of the biosphere, accurate estimates of the emergy of the human knowledge contributing to economic and social activities are needed to ensure that the environmental, economic, and social costs and benefits of alternative policies can be quantified in equivalent terms based on their respective emergy flows.

The work of people that is delivered to support economic and social activities is primarily a function of their knowledge and experience. Thus, human service can be defined as the knowledgeable work of people employed in social and economic activities. Human service is dependent on a storage of information (i.e., knowledge and experience), which requires an information cycle (Odum 1996) for its development and maintenance. As a result, human knowledge and experience have unique properties that require us to consider the role of time in their creation. First, the knowledge base of an individual or of a nation can not be generated in the course of a single year, which is the standard temporal unit used for most emergy analyses. In general, individuals go through many years of school or other training, while they accumulate enough knowledge to profitably enter the workforce. In a similar manner, the stored knowledge and experience of the people of a nation can not be generated quickly. It requires at least a generation for those trained in the various fields of knowledge to reach their full potential and to train the next generation.
A second unique aspect of human knowledge is that it is not diminished by use; in fact, it increases as individuals learn more about their fields through the application of what they have learned. Thus, the information that an individual worker can contribute grows throughout their career and as a result the emergy of their knowledge increases as does the transformity of their work. The storage of knowledge and experience of a people is diminished, ultimately, by death. Unemployment and sickness diminish its application in carrying out economic and social activities in any given year. Retirement changes the way that the knowledge of an individual is used by society and sadly aging begins to erode the knowledge of many.

The work of people with varying levels of education and experience plays a fundamental role in determining the kinds of economic and social activities that can be carried out within a society. The emergy required for much of the information stored in human knowledge and experience can be evaluated through an analysis of the education system of a nation. In this study, we evaluated the education system of the United States from 1870 to 2006 using emergy methods. First, we determined the annual emergy required for each level of education, i.e., elementary, secondary, and college. Second, we calculated the emergy required for an individual at the various levels of education from pre-school to the doctoral degree. Finally, we estimated the emergy required for the teaching and learning process. The latter activity is a higher order social process dependent on the emergy required for the transfer and reproduction of information.

Prior Emergy Evaluations of Human Service

Human service is often a high quality (i.e., high transformity feedback) interacting with lower quality material and energy resources to make value added products from the lower transformity energy and materials. Money, i.e., income and wages, is only paid to people for their work and as a result the emergy of human service can be approximated by multiplying the money flow accompanying a given task by the emergy to money ratio of the system within which the task is performed. However, Odum (1996) states that this method is only valid when the service is performed by a person with the average level of knowledge and experience found in the system being evaluated. Another method that Odum (1996) used to evaluate the different levels of human service was to divide the total national emergy flow in a given year by the number of people in a knowledge and experience category to obtain the emergy per individual in that category. The transformity (sej/J) of an individual’s labor could then be determined by dividing the annual metabolic energy (J) of an individual into the emergy (sej) required per individual at a given knowledge level. Odum (1996) presents the results of this calculation for the United States in 1980.

Both of the existing methods used to estimate the emergy of human services are approximations. The commonly used method of multiplying the money flows by the emergy to money ratio essentially uses the information of the money flow to scale the emergy estimate. The second method is better because it is based on the emergy flows supporting the system in a given year. However, it is based on the assumption that the knowledge system of the nation is in steady state and that the current distribution of people with various levels of knowledge and experience is hierarchical and that the cumulative distribution itself can be taken as the output of this process. This implies that the entire emergy input to the nation is required to produce all the people that have attained a given level of education. Since the U.S. national education system was not in steady state over the period examined, and there is a time delay in the creation of knowledge and experience, a more accurate method for determining the emergy of human service may be to analyze the education process required to generate and transfer knowledge.

Models of the U.S. Education System

A model of the education system of the United States is presented in Figure 1, where the system is divided into three subsystems, elementary, secondary, and college education. Each subsystem has its own inputs and outputs, which are quantified in the figure using values for 1980. Each pathway is also
marked with the subscripted letter, k, which in turn is entered as a line in Table 1 where the definition of the pathway is given along with its value. The emergy inputs required to run the education system at each level are shown as external sources or as internal storages of emergy that enter the box marked “Operations” (Fig. 1). Sources include the emergy input from the environment, \( k_0 \); the energy used to operate the system, \( k_1 \); the energy, \( k_9 \), and materials, \( k_{10} \), used in building construction; the new students enrolling in school, \( k_5 \); students returning to school, \( k_6 \); the goods used in construction, \( k_{11} \); the services used in construction, \( k_{12} \); the goods and services used to operate the schools, \( k_3 \); libraries and equipment, \( k_4 \); and teachers, \( k_7 \). The total annual emergy required for education in a subsystem is given by the pathway coefficient, \( k_8 \). The outputs of the education systems are graduates, \( k_{15} \), and dropouts, \( k_{14} \). College (Figure 1c) was evaluated as a combined system with outputs ranging from a two-year associate degree, \( k_{14} \); through college graduates, \( k_{15} \); master’s degree, \( k_{16} \); 3-year professional degree, \( k_{17} \); to the PhD, \( k_{18} \). College dropouts, \( k_{14} \), were assumed to have an education equivalent to the 2-year degree. The emergy per individual was modeled based on the time that a student remains in school. Thus, the difference between a PhD and an average dropout with two years of college is the emergy required to support the doctoral graduate in the school system for an additional 6 years. Doctoral candidates who spend more time in school or who complete post-doctoral fellowships have greater emergy per individual. Medical doctors, who generally spend 4 years in school upon graduation, would have an emergy per individual similar to a PhD. The depreciation of school buildings in a given year, \( k_2 \), represents the contribution of the college infrastructure to the emergy required for the education process. Books and equipment are shown as a separate storage for all subsystems, but because of the limited data available, libraries were the only aspect of this storage that we quantified explicitly and this was done only for colleges. The storage of books and equipment was quantified as part of the general expenditures on services for the other subsystems, and the emergy of college equipment, etc. was included as a part of overall college services.

The higher order social process of teaching and learning is modeled in Figure 2. The emergy of teaching and learning was quantified as the sum of the emergy delivered during the time spent transmitting the information plus the emergy brought to the learning process by the students, who were receiving the information. We assumed that the emergy of the teaching and learning process was all that was required to increase the total knowledge in the system under evaluation. Knowledge is modeled with a quadratic drain, since it is a form of information. The algorithms for calculating the emergy required for the teaching and learning process are given in Appendix A.

**METHODS**

The standard methods of Emergy Analysis (Odum 1996, Campbell et al. 2005) were used to evaluate the education system of the United States. The methods used were those appropriate for evaluating a production process. These methods were applied independently to each of three subsystems, elementary, secondary, and college, that together comprised the U.S. education system. The first step in the emergy methods for evaluating a production process is to diagram the process (Figures 1 and 2). In the process of creating the diagram appropriate spatial and temporal boundaries are determined. The spatial boundaries of this study were set to be the territorial boundaries of the United States. The temporal boundaries of the study were set by the time period evaluated, i.e., 1870 to 2006. The time period for the evaluation of the subsystems was one year. The model components, outputs and the required inputs to the education subsystems were determined from our general knowledge of the structure and function of education systems and from a prior study of the University of Florida reported in Odum (1996).

In this case the second step in the evaluation was to decide on the method that we would use to estimate the emergy of the graduates from the three subsystems. We decided to treat all students as information receptors, so that the emergy required for the information transferred in a given year would be the sum of the annual emergy inputs required to run the school subsystem. In this method, the emergy of an individual student’s education level is calculated as the sum of the emergy per individual required for each year of education summed over the time spent in school.
The third step was to systematically evaluate each of the inputs required to produce people with the various levels of education. The first task in evaluating the inputs was to find the data needed to make the evaluations. Most of the data used to evaluate the subsystems was found in the United States Statistical Abstracts: Earlier Editions (U.S. Census Bureau 2009). All volumes issued from 1870 to 2009 that were available on-line were used in this evaluation. In addition, late in the evaluation process we found and subsequently used data on the U.S. education system compiled by Snyder (1993). Also, various sources were used to fill-in critical information that was not recorded in the Statistical Abstracts: Earlier Editions. The second task in evaluating the inputs was to determine the algorithm to be used to calculate each input (see Appendix A). The value of the input was determined in the units in which it is commonly expressed, e.g., individuals for people, g for mass, J for energy, and $ for economic flows.

The fourth step in evaluating the education process of the U.S. was to convert the values for the inputs from their common units into emergy by multiplying by the appropriate emergy per unit value, i.e., the emergy per person (sej/ind) for people, the transformity (sej/J) for energy, the specific emergy (sej/g) for mass, or the emergy to money ratio (sej/$) for money flows. The emergy inputs to each subsystem were then summed to determine the emergy required to support the educational process at that level in any given year. The emergy per individual for a graduate or dropout from any subsystem was determined by summing the emergy required per pupil over the time in school. The emergy required for all earlier education including pre-school was included in the emergy per individual at higher levels of education. The transformity of the work done by an individual with a given level of education was calculated by dividing the emergy of the education level per individual by the metabolic energy expended by an individual in a year.
Table 1. Definition of the major pathway flows in the subsystems of the energy systems model of education in the United States (Figure 1). The values shown are for 1980.

<table>
<thead>
<tr>
<th>Pathway</th>
<th>Definition of Emergy Flow</th>
<th>Value X10&lt;sup&gt;22&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elementary Education (Figure 1a)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>k&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Renewable resources used on the school grounds</td>
<td>0.38</td>
</tr>
<tr>
<td>k&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Consumption of fuel and electricity to run the schools</td>
<td>4.19</td>
</tr>
<tr>
<td>k&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Depreciation of school buildings (.0333 per y)</td>
<td>13.63</td>
</tr>
<tr>
<td>k&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Service support required in addition to teachers</td>
<td>28.50</td>
</tr>
<tr>
<td>k&lt;sub&gt;4&lt;/sub&gt;</td>
<td>Books and equipment (lumped with other services in k&lt;sub&gt;3&lt;/sub&gt;)</td>
<td>NA</td>
</tr>
<tr>
<td>k&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Support for pre-school students entering school in the fall</td>
<td>15.91</td>
</tr>
<tr>
<td>k&lt;sub&gt;6&lt;/sub&gt;</td>
<td>Support for students returning to school in the fall</td>
<td>141.92</td>
</tr>
<tr>
<td>k&lt;sub&gt;7&lt;/sub&gt;</td>
<td>Support for teachers (purchased with their salaries)</td>
<td>13.31</td>
</tr>
<tr>
<td>k&lt;sub&gt;8&lt;/sub&gt;</td>
<td>Total emergy required to support Elementary education</td>
<td>217.84</td>
</tr>
<tr>
<td>k&lt;sub&gt;9&lt;/sub&gt;</td>
<td>The energy used in building construction</td>
<td>0.24</td>
</tr>
<tr>
<td>k&lt;sub&gt;10&lt;/sub&gt;</td>
<td>The minerals used in building construction</td>
<td>6.29</td>
</tr>
<tr>
<td>k&lt;sub&gt;11&lt;/sub&gt;</td>
<td>Goods purchased for building construction</td>
<td>3.89</td>
</tr>
<tr>
<td>k&lt;sub&gt;12&lt;/sub&gt;</td>
<td>Services used in building construction</td>
<td>1.51</td>
</tr>
<tr>
<td>k&lt;sub&gt;13&lt;/sub&gt;</td>
<td>Total emergy of new construction.</td>
<td>11.88</td>
</tr>
<tr>
<td>k&lt;sub&gt;14&lt;/sub&gt;</td>
<td>Emergy of dropouts with an average 5&lt;sup&gt;th&lt;/sup&gt; Grade education</td>
<td>4.89</td>
</tr>
<tr>
<td>k&lt;sub&gt;15&lt;/sub&gt;</td>
<td>Emergy of a student completing the 8&lt;sup&gt;th&lt;/sup&gt; grade</td>
<td>232.66</td>
</tr>
<tr>
<td><strong>Secondary Education (Figure 1b)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>k&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Renewable resources used on the school grounds</td>
<td>0.22</td>
</tr>
<tr>
<td>k&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Consumption of fuel and electricity to run the schools</td>
<td>2.49</td>
</tr>
<tr>
<td>k&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Depreciation of school buildings (.0333 per y)</td>
<td>8.10</td>
</tr>
<tr>
<td>k&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Service support required in addition to teachers</td>
<td>14.08</td>
</tr>
<tr>
<td>k&lt;sub&gt;4&lt;/sub&gt;</td>
<td>Books and equipment (lumped with other services in k&lt;sub&gt;3&lt;/sub&gt;)</td>
<td>NA</td>
</tr>
<tr>
<td>k&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Support for 8&lt;sup&gt;th&lt;/sup&gt; Grade graduates entering high school in the fall</td>
<td>17.39</td>
</tr>
<tr>
<td>k&lt;sub&gt;6&lt;/sub&gt;</td>
<td>Support for high school students returning to school in the fall</td>
<td>60.79</td>
</tr>
<tr>
<td>k&lt;sub&gt;7&lt;/sub&gt;</td>
<td>Support for teachers (purchased with their salaries)</td>
<td>10.30</td>
</tr>
<tr>
<td>k&lt;sub&gt;8&lt;/sub&gt;</td>
<td>Total emergy required to support High School education</td>
<td>113.16</td>
</tr>
<tr>
<td>k&lt;sub&gt;9&lt;/sub&gt;</td>
<td>The energy used in building construction</td>
<td>0.15</td>
</tr>
<tr>
<td>k&lt;sub&gt;10&lt;/sub&gt;</td>
<td>The minerals used in building construction</td>
<td>3.74</td>
</tr>
<tr>
<td>k&lt;sub&gt;11&lt;/sub&gt;</td>
<td>Goods purchased for building construction</td>
<td>2.31</td>
</tr>
<tr>
<td>k&lt;sub&gt;12&lt;/sub&gt;</td>
<td>Services used in building construction</td>
<td>0.90</td>
</tr>
<tr>
<td>k&lt;sub&gt;13&lt;/sub&gt;</td>
<td>Total emergy of new construction.</td>
<td>7.06</td>
</tr>
<tr>
<td>k&lt;sub&gt;14&lt;/sub&gt;</td>
<td>Emergy of H.S. dropouts with an average 10&lt;sup&gt;th&lt;/sup&gt; Grade education</td>
<td>65.89</td>
</tr>
<tr>
<td>k&lt;sub&gt;15&lt;/sub&gt;</td>
<td>Emergy of a student completing high school</td>
<td>291.83</td>
</tr>
<tr>
<td><strong>College Combined (Figure 1c)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>k&lt;sub&gt;0&lt;/sub&gt;</td>
<td>Renewable resources used on the school grounds</td>
<td>0.16</td>
</tr>
<tr>
<td>k&lt;sub&gt;1&lt;/sub&gt;</td>
<td>Consumption of fuel and electricity to run the schools</td>
<td>3.78</td>
</tr>
<tr>
<td>k&lt;sub&gt;2&lt;/sub&gt;</td>
<td>Depreciation of school buildings (.0333 per y)</td>
<td>12.29</td>
</tr>
<tr>
<td>k&lt;sub&gt;3&lt;/sub&gt;</td>
<td>Service support required in addition to teachers</td>
<td>26.50</td>
</tr>
<tr>
<td>k&lt;sub&gt;4&lt;/sub&gt;</td>
<td>Library Books</td>
<td>0.97</td>
</tr>
<tr>
<td>k&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Support for High School graduates entering college in the fall</td>
<td>10.00</td>
</tr>
<tr>
<td>k&lt;sub&gt;6&lt;/sub&gt;</td>
<td>Support for college students returning to school in the fall</td>
<td>54.38</td>
</tr>
<tr>
<td>k&lt;sub&gt;7&lt;/sub&gt;</td>
<td>Support for teachers (purchased with their salaries)</td>
<td>9.05</td>
</tr>
<tr>
<td>k&lt;sub&gt;8&lt;/sub&gt;</td>
<td>Total emergy required to support education</td>
<td>117.12</td>
</tr>
<tr>
<td>k&lt;sub&gt;9&lt;/sub&gt;</td>
<td>The energy used in building construction</td>
<td>0.22</td>
</tr>
<tr>
<td>k&lt;sub&gt;10&lt;/sub&gt;</td>
<td>The minerals used in building construction</td>
<td>5.67</td>
</tr>
<tr>
<td>k&lt;sub&gt;11&lt;/sub&gt;</td>
<td>Goods purchased for building construction</td>
<td>3.51</td>
</tr>
<tr>
<td>k&lt;sub&gt;12&lt;/sub&gt;</td>
<td>Services used in building construction</td>
<td>1.36</td>
</tr>
</tbody>
</table>
Teaching and learning was evaluated as a higher order social process requiring the emergy of the interacting inputs. The emergy delivered in the teachings conducted in a subsystem is the emergy of the teacher’s education and experience per individual times the fraction of hours spent teaching times the number of teachers. The student’s emergy, which is required to receive the information, is that of their average education level per individual times the fraction of hours spent learning times the enrollment. The sum of these two inputs is the emergy of teaching and learning that occurs within each subsystem. The sum of the three subsystems is the emergy of teaching and learning occurring within the United States in any year.

RESULTS

An emergy evaluation of the education system of the United States in 1980 is shown in Figure 1, and the pathways of the three subsystems are defined in Table 1. The pathway coefficients, the k’s in Figure 1 a, b, and c, can be used to identify model pathways in Table 2. The subscripted letter k was
Table 2. Emergy per individual and transformity for different education levels in 1980.

<table>
<thead>
<tr>
<th>Attainment</th>
<th>Odum 1996</th>
<th>This study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Emergy/ind.</td>
<td>Transformity*</td>
</tr>
<tr>
<td></td>
<td>(E+16 sej/ind./y)</td>
<td>(E+6 sej/J)</td>
</tr>
<tr>
<td>Preschool</td>
<td>3.4/7.2</td>
<td>8.9/18.9</td>
</tr>
<tr>
<td>School</td>
<td>9.4/19.9</td>
<td>24.6/52.1</td>
</tr>
<tr>
<td>College Graduate</td>
<td>28.0/59.4</td>
<td>73.3/155.5</td>
</tr>
<tr>
<td>Masters (Post College Ed.)</td>
<td>131.0/277.9</td>
<td>343.0/727.5</td>
</tr>
<tr>
<td>Professional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PhD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public Status</td>
<td>393.0/832.6</td>
<td>1029.0/2179.6</td>
</tr>
<tr>
<td>Legacies</td>
<td>785.0/1665.2</td>
<td>2054.0/4359.2</td>
</tr>
</tbody>
</table>

The emergy and transformity values for educational attainment levels from Odum (1987, 1996) are reported first using the emergy base for the U.S. determined by Odum (1987) and second the emergy base for the U.S. as determined by Campbell and Lu (2009).

* Energy per individual: (2500kcal/day)*(365days/yr)*(4186J/kcal) =3.82E09J/ind./yr
* Public Status assuming that 1% of the population meets this criterion.

repeated for similar flows in each subsystem. The model was evaluated for 1980, but values for any year can be substituted on the diagram. In 1980, the empower of elementary education was 1.93 times that of high school education and 1.86 times that of the college subsystem. Figure 3 shows that this relationship has varied over time, and that the empower of elementary education has exceeded that of the other two subsystems over the entire time period. The empower of college education first exceeded high school education in 1980, when it was 3.5% greater than high school. After 1986, the empower supporting both college and elementary education began to increase rapidly, but this time was delayed until 1993 for high school. The structure of the required inputs to all three subsystems follows a similar general pattern with some differences. Returning students were always the largest input to the subsystems, but the second most important input varied among the systems and over time. Purchased services are relatively more important in the college subsystem than in the elementary and secondary subsystems. The emergy of the inputs to all three education systems increased over time from 1870 to 2006, with the exception of the input of emergy from the environment to elementary education.

Figure 2 shows the emergy inputs to the process of teaching and learning in the three education subsystems for the 1979 to 1980 school year. In that year, the amount of information transferred as measured by the emergy of the process was similar in all three subsystems. The annual emergy used by the high school subsystem exceeded the elementary subsystem by 1%, and the emergy use of the college subsystem exceeded the elementary system by 6.25%. The emergy of the process of teaching and learning in 1980 exceeded the annual emergy required for operations by 6.52 times for elementary, 12.70 times for secondary, and 12.90 times for college education. Figure 4 shows the time history of variation in the emergy of teaching and learning in the three U.S. education subsystems from 1870 to 2006. Until 1977 the emergy of teaching and learning is greatest at the elementary level. After 1977 high school was briefly the largest emergy until 1980 when teaching and learning at the college level became the largest. Since 1980, except for a brief period from 1992 to 1995, teaching and learning in the college subsystem has continued to increase maintaining its position as the largest educational activity in the U.S. as measured by its emergy over this entire time. Teaching and learning in the elementary subsystem declined slowly from 1976 to 1987 after which it began to increase. The high school subsystem declined from 1979 to 1990 and then began to increase at a rate similar to that experienced by college and elementary schools. In 1996, the rate of increase in the emergy of teaching and learning in the college subsystem became more rapid, separating it from the rates of increase of both the elementary and secondary education subsystems.

Time series for the emergy per individual for ten education levels from pre-school to the doctoral degree are shown in Figure 5. The numerical values for the emergy per individual at these education
levels are given in Appendix B. The emergy per individual in all categories declined from 1870 to 1900. After the turn of the century the emergy per individual began to increase and it continued to do so in all categories with some variation until around 1950. After 1950 the emergy per individual increased almost monotonically for college students, and with the exception of the period from 1982 to 1992, a similar increase is observed for the elementary and secondary subsystems.

In Table 2, the emergy per individual calculated in this study is compared to the earlier results of Odum (1996). Odum’s results are given as originally calculated and after adjusting the calculation using the new emergy base for the United States in 1980 given in Campbell and Lu (this volume). The
college educations by 59.9%, 162.8%, and 115.4%, respectively. However, Odum’s estimate for post-college education exceeds our estimate by 76.5%. If one percent of the population has attained public status as we assumed, Odum’s estimate for the emergy per individual with public status is 13% greater than the estimate made in this study. “Public Status” implies that an individual controls energy, material, and information flows much larger than expected for a person with their education and experience levels, e.g., a public official managing a National Park, or the CEO of a company.

DISCUSSION

Economic flows of energy, materials and labor are quantified most often in monetary units; whereas, emergy analysis needs information quantified in units of mass, energy or information. Estimating the emergy equivalent of a monetary flow is sometimes the only possible way to quantify all the inputs to a production process or a system. The emergy to money ratio is the metric commonly used to convert money flow expressed in dollars to an emergy flow. Recently, Pizzigallo and Campbell (accepted) have shown that these estimates can be made more accurate by adjusting the monetary measure using the Emergy Yield Ratio of the product or service. Nevertheless, it would be better to have an independent measure of the emergy flow for which the dollars are paid. In this paper we made a quasi-independent estimate of the emergy for which a quantity of money is paid, assuming that money is paid only for the human services required for the product or service, i.e., no money is paid for the work of the environment, and that the education level of the worker is largely responsible for the quality of the work performed. Our estimate of the transformity of human knowledge was based on quantifying the emergy required for the education of an individual, which we assumed captured most of the value of the work for which money was paid. As described above, human knowledge was quantified through performing an emergy analysis of the U.S. education system from 1870 to 2006. The value of experience was also quantified, but in this case only for teachers. Similar methods might
be used to quantify the emergy of experience for other occupations as this method matures. A relatively independent estimate of the emergy flow for which money is paid will allow us to calculate the emergy of educational attainment in the United States over time and to include this input as part of the emergy basis for characterizing and analyzing socioeconomic activities of the Nation.

Odum (1996) estimated the emergy of human service at the various education levels by assuming that the total emergy inflow to the Nation in a year supported the observed distribution of educational attainment. The number of people that had achieved each level of attainment was divided into the emergy base for the nation in that year to estimate the emergy per individual with a given level of education. The output was a series of transformities that increased with education level, because almost everyone had achieved a preschool level of education, but only 6 million people had post college education. This method assumes that the system is in steady state and that all of the emergy input to the Nation was required to produce the hierarchy of observed education levels in the year evaluated. In this paper, we estimated the emergy of human service based on an emergy evaluation of the education system in the United States under the assumption that the emergy supporting an individual in this system, when summed over the time spent in school, was what was required to produce an individual with a given level of education. This method does not need to assume that the system is in steady state nor does it assume that the entire emergy of the Nation is required to produce the individuals at each education level. Our method based on the cumulative emergy of education resulted in a higher assessment of the emergy per individual for college graduates, secondary education, elementary education and preschool, but a lower estimate for post graduate education. This result is due to Odum’s use of the total number of people who had attained an education level as the basis for his calculation compared to our use of summation over the years in school up to the final level of education attained. Odum’s method is more holistic and top-down in its approach to the problem, but it has some significant difficulties related to the reasonableness of its underlying assumptions. The method used in this paper makes the plausible argument that all students learn from their time in school and that all other things being equal the emergy required for a step in learning is proportional to the emergy required to support the pupil during their time in school. Of course, all other things are not equal because pupils vary in intelligence, dedication to their studies, learning styles as well as in other ways. These secondary factors were not considered in this analysis. Given the fact that the two methods are very different in their approach it is encouraging that the results from both methods are in the same “ballpark” and that the variation is consistent with the difference expected from the inherent characteristics of the calculation methods used in the two approaches.

We performed a cursory analysis of patterns observed in the time series of variables used to characterize the three education subsystems. This data set is rich in information, but it was not necessary for us to delve into the dynamics of the system in depth for this study. A few observations on the patterns observed in Figures 3-5 are given below. We noticed a broad pattern of increase in all inputs to the subsystems over the entire period of the analysis except for the input from the environment to the elementary education system and to a lesser extent from the environment to the secondary education system. Input from the environment to the elementary school system peaked from 1927 to 1929 after which it rapidly declined, apparently due to the consolidation of small schools into larger ones, thus requiring less total land area. The pulse with a long increase and rapid decline, which is seen in the temporal pattern of the emergy required to support the elementary and secondary school systems from 1960 to the late seventies (Figure 3), can be explained by the population cycle driven by the post WWII “baby boom”. The consistent decline in the emergy per individual at all education levels from 1870 to 1900 is due to factors not related to the efficacy of the work performed by a person of a given educational status. This pattern is seen because the number of pupils enrolled in school at all levels increased rapidly during this period, while the emergy of the inputs to the educational system increased less rapidly.

This was not an easy emergy analysis to carry-out and we had to overcome many technical obstacles along the way. One of the primary obstacles was that we wanted to estimate the emergy of an individual with a given level of education independent of the monetary value of inputs, i.e., without
using the emergy to money ratio of the Nation to determine the emergy of the education levels. This proved to be a task beyond our capabilities; therefore, we settled for a quasi-independent estimate using the emergy equivalent of money only when absolutely necessary. Even though we used the emergy to money ratio to estimate the support emergy for students and teachers, as well as the services required for school operation and construction, most other inputs were estimated from the energy and material flows, and therefore we believe that we have a valid, first-order, quasi-independent estimate of the emergy per individual at the various education levels in the United States from about 1900 to 2006. We do not recommend that the years from 1870 to 1899 be used as accurate estimates of the emergy per individual, since we allotted this time for the calculation to stabilize (see below).

A second difficulty was that we needed to know the initial condition of several variables, e.g., the emergy of school buildings, the emergy of teacher’s education, etc., in order to make an accurate estimate of the emergy required for education. We negotiated this problem by starting our analysis in 1870 rather than in 1900. We started the system analysis with the known or estimated flows in 1870 and allowed the evaluation to “spin up” similar to a mathematical model, so that in about 10 years the output variables had stabilized and were following reasonable trends. Our initial estimates might be improved in the future by applying an iterative approach to the calculation of the emergy of the education levels by constructing a model and feeding back the current estimates as initial conditions and annual inputs iteratively until a stable value for the emergy per individual at each education level is reached.

There is a lack of consistency in some of the numbers currently used in our evaluation for some years. These variations occur because the U.S. Census Bureau reports many different variations of a number like elementary enrollment. In addition, one method will be used for a series of years and then changed, leading to different estimates. In addition, initial values often are refined in subsequent years, so it was difficult to eliminate all inconsistencies from the reported values of some variables. This inconsistency leads to some noise in the data, but it is not great enough to affect the results of this study. In general, variations are within the 10% limit that is acceptable for emergy analyses (Campbell et al. 2005). Also, many variables that were used in this analysis had missing data for one or more years. We handled missing data using three techniques, interpolation, extrapolation, and estimation. Interpolation and extrapolation were used when we had values for many years over the 136 year period. Estimation was used when we had little information and needed to impute reasonable values for a variable. Linear interpolation between two known values and proportionate extrapolation using the relationship between a known variable and the unknown to assign values to the unknown were used to assign values to the years with missing data.

Odum (1996) described the method for calculating the emergy of teaching and learning, but apparently he never made the calculation. Our calculation of the emergy of teaching and learning is one of the first calculations of the emergy of a social process. The emergy of teaching and learning is a measure of the emergy required for copying or transferring information, as such it is a higher order social function and it has a transformity approximately an order of magnitude greater than that required for the annual support of the U.S. education system. The implication of this result is that the emergy spent on education has a 10:1 return on investment in terms of the overall benefits gained by society.

ACKNOWLEDGMENTS

This paper is contribution number AED-10-015 of the U.S. EPA’s Office of Research and Development, National Health and Environmental Effects Research Laboratory (NHEERL), Atlantic Ecology Division (AED). Cathy Wigand, Walt Galloway, Giancarlo Cicchetti of AED and Denis White of NHEERL’s Western Ecology Division provided helpful internal reviews of this paper. Although the research in this paper was funded in part by the USEPA, it has not been subjected to Agency-level review; therefore, it does not necessarily reflect the views of the USEPA.
REFERENCES

Long term data was found accessed on Nov 23, 2009 from http://www.wou.edu/las/physci/GS361/electricity%20generation/US_consumption_1635-1945.htm
Last modified October 5, 2009.

479
APPENDIX A. CALCULATION OF THE EMERGY INPUTS TO EACH LEVEL OF THE U.S. EDUCATION SYSTEM

This appendix is organized by input, so that the calculation methods, data and sources for all subsystems are discussed within each input category.

Environment:

The area supporting each of the education subsystems was estimated by multiplying the average area of the school grounds by the number schools active in a given year. The total number of schools in each subsystem was determined from data recorded in the U.S. Statistical Abstracts. Estimates for the average acreage of U.S. elementary (1 acre for 1 room and 10 acres for multi-room schools) and secondary (15 acres) schools were taken from Filardo (2008). Data on the average area of different types of U.S. colleges was found in Dober (1964). The number of schools in different categories of colleges was multiplied by the average number of acres for a school of that type (61 acres for private college and 154 acres for public college) the categories were summed to estimate the total land area for colleges in the U.S. The renewable empower for the United States and the emergy of erosion (Campbell and Lu, this volume) were used to quantify the emergy contributions of the environment to support the education subsystems. Total use of renewable emergy and the emergy input due to erosion were divided by the area of the nation to obtain the average empower density (sej/m²) of environmental inputs. We assumed that 68% of the school grounds was school yard and subject to erosion based on a study by Schulman and Peters (2008). The environmental emergy contributing to each education subsystem was calculated by multiplying the area (m²) by the renewable empower density of the U.S. and adding 0.68 times the area times the empower density of erosion.

Energy Consumed:

The energy used to operate the buildings in each education subsystem was estimated using data obtained from the Energy Information Administration (2009). Statistics were available on commercial energy use in the United States from 1949 to 2006. The data were given as BTUs consumed by energy type, including, biomass, coal, petroleum, natural gas, and electricity. Longer term data on energy consumption in the U.S. from 1635 to 1945 were also found on the EIA website. The area of school buildings in each subsystem from 1870 to 2006 was estimated below under building construction. The average fraction of total commercial energy use accounted for by education in the five energy types mentioned above was given for eight years within the time period 1979 to 2003 (EIA 2009). This data was used to estimate the energy used by education buildings in each of the 5 energy types. After 1948 the emergy used in each subsystem was calculated by multiplying the average number of BTUs used of each type of energy in a year by the fraction of the total building area accounted for by that subsystem times 1055 J/BTU times the transformity of the energy used. The transformities of the types of energy used in this study were biomass, 20600 sej/J, coal, 37800 sej/J, natural gas, 43500 sej/J, petroleum 65800 sej/J, and electricity 170400 sej/J (Campbell and Ohrt, 2009). Detailed data on education and commercial building energy use were not available prior to 1949. Therefore, the average rate of energy use per square foot for education buildings from 1870 to 1948 was assumed to be similar to that calculated for 1949. Prior to 1949, the algorithm for determining the emergy of energy use was to multiply the average total energy use per sq. ft. by the fraction of that type of energy used nationally times the area of buildings in the subsystem times the conversion from BTUs to Joules times the transformity of the energy type. In both algorithms given above, the summation over all energy sources in a year gave the emergy used to support buildings for the education subsystem in that year.

Building Construction:

U.S. Census Bureau (2009) contains estimates of the dollar value of new public and private construction put in place from 1915 to 1970. The value of public education buildings put in place was given from 1919 to 1970. In addition, the value of contracts awarded in education and science and the floor space to be built were also recorded. From this data the average cost of construction per square foot was determined. The average cost per sq. ft. was divided into the cost of public school construction put in place to estimate the area of public school buildings built in a given year. From 1993 to 2006, the U.S. Census Bureau (2009) gives detailed data on the cost of public and private school construction. The average fraction of private to public construction costs was used to adjust the area of schools built under the assumption that the cost for building a school was about the same regardless of the source of funds.

The value of all new construction awarded in the U.S from 1870 to 1919 was available in the U.S. Statistical Abstracts. We applied the ratio of education construction to total construction in 1919 back to 1870 to estimate the value of new school construction. We applied the average cost per sq. ft. ($6.05 sq. ft.) during the relatively stable period from 1919 to 1943 to estimate the area of public education buildings constructed during that time. The area of schools built from 1870 to 2006 was partitioned into subsystems using the detailed data on public and private school construction by education level that was reported from 1993 to 2006. This information was also used to

480
calculate the fraction of total cost that applied to each subsystem. About 14% of the construction costs were assigned to other educational buildings, e.g., museums, libraries, etc.

The emergy inputs to the school buildings built in each subsystem were determined using the material and labor requirements for constructing public buildings (Olsen, 1981). The classes of material inputs along with their emergy per unit values are as follows: (1) Minerals and raw materials including lumber and wood products, 5.18E+08 sej/g; paper, 3.25E+09 sej/g; chemicals, 2.75E+09 sej/g; petroleum refining and related products, 6.58E+04 sej/J; stone, glass, and concrete, 1.96E+09 sej/g; primary metal, 5.91E+09 sej/g; and (2) Goods including fabricated metal 5.91E+09 sej/g; machinery except electrical 7.76E+09 sej/g; electrical machinery 7.76E+09 sej/g; instruments and related products 7.76E+09 sej/g; and misc. manufactured products sej/g 7.76E+09. References for the specific emergies used for these materials are given in Campbell and Ohrt (2009).

The emergy of the services required for construction was calculated using the average dollar value of construction times the emergy to money ratio for the year in which the construction was put in place. The energy cost of building construction was taken from Stein (1977), who estimated that 1.3 E+06 BTUs were required per sq. ft. built. This value was applied uniformly over time using the area built to estimate energy requirements for building construction. The emergy of the energy used in construction was determined by multiplying the energy required for the area built by the fraction of energy of each type available to support building construction in that year times the transformity of the energy used. The energy requirements for construction were summed to determine the emergy of the school buildings constructed in each year. New construction was summed to estimate the area of buildings in service at any given time after diminishing the existing area by 0.033, a factor equivalent to a 30 year replacement time. New construction put in place was assumed to come into service on the half year, thus new construction was also subject to depreciation of 0.0167 per year. The energy lost through the depreciation of the buildings in service was assumed to be the emergy supplied by the infrastructure in support of the education process carried on by each subsystem.

Services:

The total expenditures for public elementary and secondary schools from 1870 to 2006 are recorded in the U.S. Census Bureau (2009). Private school expenditures were recorded in some years from 1910 to 1970, after which they were recorded annually. We used linear interpolation to fill in the missing years and we estimated private expenses prior to 1910 assuming that private expenses on education were about 10% of the public expenses, as estimated from years when both values were known. Expenditures were portioned into elementary and secondary categories based on enrollment. The dollar values of elementary and secondary expenditures minus teacher salaries are considered to be the service input to these education subsystems. Dollar values were converted to emergy using the emergy to money ratio calculated by Campbell and Lu (this volume). We estimated the emergy to dollar ratio of the U.S. from 1870 to 1899 for this study and for the years before 1900, we applied it to make estimates of the emergy equivalent of dollar values. College expenditures were recorded after 1930 and several different aggregations are reported. For this study we used the largest measure of expenses and diminished it by the cost of teacher salaries and library operations. Library operations were added into the emergy of college inputs as a separate item. Before 1900 college expenses were not recorded, so we estimated the values for earlier years using the ratio of college expenses to combined elementary and secondary expenses in 1900 and extrapolated back to 1870.

New Students Entering:

The average disposable income per capita in the U.S. in the year evaluated times the emergy to money ratio for that year was used to determine the support emergy allocated to each student in all subsystems. The new students entering elementary school in the fall were estimated by adding the entering kindergarten students to the 1st grade students and subtracting last year’s kindergarten students. Data on kindergarten and 1st grade enrollment was taken from Snyder (1993), although it also appears in the U.S. Census Bureau (2009). The new students entering elementary school were multiplied by the emergy per capita as determined above to estimate the emergy supporting the students entering elementary school. Eighth graders going on to high school were estimated as the 9th grade enrollment in the fall. The emergy supporting new students entering high school was calculated as for elementary students. Data on the percent of students graduating from high school each year was found in the U.S. Census Bureau (2009). The percent of high school graduates going on to college was also given in one format from 1931 to 1979 and in another format from 1984 until 2003. Missing data from 1979 to 2003 was supplied by linear interpolation; the value for 2003 was applied in 2004-2006, and a linear regression of the data set from 1931 to 2006 was used to extrapolate values back to 1870. The number of new students entering college was multiplied by the emergy per capita used for their support to determine the emergy of newly entering college students.

Returning Students:

The emergy of returning elementary students was calculated as last year’s enrollment minus the 8th graders going on to high school minus dropouts. The support emergy assigned to returning students in all three subsystems.
was the emergy per capita calculated from disposable income and the emergy to money ratio. Initially returning high school students were calculated as high school enrollment in the previous year minus high school graduates minus dropouts. Because of irregularities in the data we changed the method of estimating returning high school students by adjusting the number of dropouts so that enrollment of new and returning students would give the correct enrollment in a given year. We handled returning college students in a manner similar to that used for high school students, i.e., high school graduates entering college and returning students were forced to sum to enrollment using dropouts as the adjustment factor. In some years, this implied that “Dropouts” was a positive number and thus extra enrollment had to matriculate from some source, e.g., former dropouts returning to college.

*Teachers:*  
Data on public elementary and secondary teachers has been recorded by the U.S. Census Bureau (2009) at least since 1870. The ratio of public to private enrollment was used to estimate the total number of teachers from the number of public school teachers. The total number of teachers was separated into elementary and secondary subsystems based on elementary and secondary enrollment assuming that the student teacher ratios were similar. Salaries for public school teachers have also been recorded since 1870. We used the salary estimates for both elementary and high school teachers and multiplied by the number of teachers and the emergy to money ratio for the economy in the appropriate year to determine the emergy supporting teachers at the elementary and secondary levels. College teacher salaries have been recorded since 1958 (U.S. Census Bureau, 2009). Between 1930 and 1958 college salaries were not recorded, but we estimated them from the number of teachers and the total expenses for instruction. Prior to 1930 college teacher salaries were estimated using the ratio of college salaries to elementary and secondary salaries in 1930. The emergy supporting college teachers was determined in a manner similar to that used for elementary and secondary teachers.

*Dollar Flows:*  
The dollar flows shown in Figure 1 were taken from data contained in U.S. Census Bureau (2009). Data on public school expenditures is complete back to 1870. Missing data on private expenditures were handled in a manner similar to that described for estimating private enrollment and teachers. Data on revenues was not quite as complete as that for expenditures. Before 1890, revenues were estimated from their ratio to expenditures in that year.

*Emergy of Teaching and Learning:*  
The emergy per individual of a graduate at any level of education is the summation of the emergy required to keep them in school for the period of time needed to attain that level. The emergy of a person’s experience is estimated assuming that people learn something new about 10% of the time that they are performing their jobs. Destre et al. (2008) found that workers can learn almost 100% of the new knowledge available to them after taking a new job within 10 years time. Thus, our estimate of 10% of the time on the job spent learning either from self-study or from others may be reasonable. The emergy per teacher is the emergy of the education level of the teacher determined based on the time they actually attended school, plus 10% of the emergy required to support their teaching activities in a year summed over their years of experience. Thus both the emergy of a teacher’s education and experience in the current year are determined using appropriate summations over past years when they obtained their knowledge.

The emergy per individual that students bring to the learning process was determined similarly. A student’s level of knowledge is the sum of the emergy required for their education up to the current year. A student is still learning, so they do not also get credit for experience, since their experience is captured in their learning. When determining the emergy of the teaching and learning process, the emergy per individual for the students and teachers is divided by their metabolic energy use in a year to give an emergy delivered per hour of their work. The emergy delivered per hour of work is multiplied by the hours of work (teaching and learning) and then multiplied by the number of individuals engaged in this activity to give the annual emergy of this process in a subsystem or in the U.S. educational system. The sum over all subsystems gives the emergy of teaching and learning in the United States as a whole in any given year.

### APPENDIX B. Emergy per Individual for Different Education Levels in the United States from 1870 to 2006 ($\times 10^{16}$sej/ind.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Pre-School (5th Grade Education)</th>
<th>Elementary Education</th>
<th>8th Grade Education</th>
<th>High School Education (10-11)</th>
<th>High School Graduate</th>
<th>Some College Degree</th>
<th>College Graduate</th>
<th>Master's Degree</th>
<th>Professional Degree</th>
<th>Doctoral Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1870</td>
<td>7.33</td>
<td>32.95</td>
<td>45.76</td>
<td>54.39</td>
<td>63.01</td>
<td>83.08</td>
<td>103.15</td>
<td>123.23</td>
<td>133.26</td>
<td>143.30</td>
</tr>
<tr>
<td>1871</td>
<td>7.13</td>
<td>32.52</td>
<td>45.33</td>
<td>54.19</td>
<td>62.81</td>
<td>83.32</td>
<td>103.39</td>
<td>123.46</td>
<td>133.49</td>
<td>143.53</td>
</tr>
<tr>
<td>1872</td>
<td>6.95</td>
<td>31.99</td>
<td>44.80</td>
<td>53.53</td>
<td>62.59</td>
<td>83.32</td>
<td>103.38</td>
<td>123.45</td>
<td>133.48</td>
<td>143.52</td>
</tr>
<tr>
<td>1873</td>
<td>6.83</td>
<td>31.39</td>
<td>44.20</td>
<td>52.97</td>
<td>62.36</td>
<td>83.11</td>
<td>103.07</td>
<td>123.14</td>
<td>133.17</td>
<td>143.21</td>
</tr>
<tr>
<td>Year</td>
<td>Average</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
<td>------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1874</td>
<td>30.71</td>
<td>43.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1875</td>
<td>30.96</td>
<td>42.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1876</td>
<td>38.91</td>
<td>41.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1877</td>
<td>28.24</td>
<td>40.99</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1878</td>
<td>27.64</td>
<td>39.98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1879</td>
<td>26.99</td>
<td>38.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1880</td>
<td>26.39</td>
<td>37.86</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1881</td>
<td>25.83</td>
<td>37.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1882</td>
<td>25.36</td>
<td>36.38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1883</td>
<td>24.93</td>
<td>35.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1884</td>
<td>24.62</td>
<td>35.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1885</td>
<td>24.33</td>
<td>34.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1886</td>
<td>24.00</td>
<td>33.79</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1887</td>
<td>23.37</td>
<td>33.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1888</td>
<td>23.44</td>
<td>33.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1889</td>
<td>23.06</td>
<td>32.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1890</td>
<td>22.71</td>
<td>32.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1891</td>
<td>22.54</td>
<td>31.95</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1892</td>
<td>22.48</td>
<td>31.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1893</td>
<td>22.22</td>
<td>31.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1894</td>
<td>21.91</td>
<td>30.74</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1895</td>
<td>21.76</td>
<td>30.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1896</td>
<td>21.64</td>
<td>30.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1897</td>
<td>21.31</td>
<td>29.94</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1898</td>
<td>21.01</td>
<td>29.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1899</td>
<td>20.82</td>
<td>29.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1900</td>
<td>20.25</td>
<td>28.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1901</td>
<td>19.68</td>
<td>27.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1902</td>
<td>19.93</td>
<td>28.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1903</td>
<td>20.01</td>
<td>28.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1904</td>
<td>20.37</td>
<td>28.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1905</td>
<td>19.31</td>
<td>28.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1906</td>
<td>19.76</td>
<td>28.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1907</td>
<td>22.69</td>
<td>28.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1908</td>
<td>22.44</td>
<td>28.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1909</td>
<td>22.85</td>
<td>29.41</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1910</td>
<td>23.00</td>
<td>32.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1911</td>
<td>23.21</td>
<td>31.88</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1912</td>
<td>25.09</td>
<td>32.54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1913</td>
<td>25.50</td>
<td>33.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1914</td>
<td>25.80</td>
<td>33.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1915</td>
<td>25.72</td>
<td>35.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1916</td>
<td>25.12</td>
<td>35.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1917</td>
<td>26.51</td>
<td>35.46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1918</td>
<td>26.22</td>
<td>35.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1919</td>
<td>25.95</td>
<td>35.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1920</td>
<td>25.68</td>
<td>36.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1921</td>
<td>24.36</td>
<td>35.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1922</td>
<td>25.92</td>
<td>35.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1923</td>
<td>25.50</td>
<td>33.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1924</td>
<td>25.80</td>
<td>35.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1925</td>
<td>25.72</td>
<td>35.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1926</td>
<td>26.51</td>
<td>35.46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>26.22</td>
<td>35.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1928</td>
<td>25.95</td>
<td>35.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td>25.68</td>
<td>36.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td>24.36</td>
<td>35.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1931</td>
<td>25.92</td>
<td>35.91</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1932</td>
<td>25.50</td>
<td>33.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>25.80</td>
<td>35.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1934</td>
<td>25.72</td>
<td>35.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1935</td>
<td>26.51</td>
<td>35.46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1936</td>
<td>26.22</td>
<td>35.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1937</td>
<td>25.95</td>
<td>35.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1938</td>
<td>25.68</td>
<td>36.52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>